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Technical Report No. 51

STATISTICAL PERT: AN IMPROVED SUBNETWORK ANALYSIS PROCEDURE

by

R. L. Sielken Jr., H. O. Hartley, R. K. Spoeri

Texas A&M Research Foundation Office of Naval Research Contract N00014-68-A-0140 Project NR047-700

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ATTACHMENT I

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THEMIS OPTIMIZATION RESEARCH PROGRAM .
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ATTACHMENT II

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#### **ABSTRACT**

R. L. Sielken Jr., H. O. Hartley, R. K. Spoeri

Statistical PERT is a new procedure for obtaining information about the distribution of a project's completion time when the project is comprised of a large number of activities and the time required to complete an individual activity once it can be begun is a random variable. The project is represented as an acyclic network whose arcs correspond to the project activities. This network is simplified by replacing various activity configurations by single equivalent activities and then decomposed into several subnetworks. The distribution and moments of each subnetwork's completion time are bounded and approximated on the basis of two points from each activity's completion time distribution by using some mathematical programming techniques and a new result in the theory of networks. The project's completion time distribution is then approximated by combining the approximate subnetwork distributions.

This report describes several refinements in the subnetwork analysis procedure. One major refinement greatly reduces the computational effort in obtaining bounds on the project completion time moments and distribution. A second major refinement allows the two-point approximation of an activity's completion time distribution to better represent skewed distributions. The computer programs required to implement the new subnetwork analysis procedure are listed and documented.

Statistical PERT: An Improved Subnetwork Analysis Procedure

R. L. Sielken Jr., H. O. Hartley, R. K. Spoeri

The well-known Program Evaluation and Review Technique (PERT) is concerned with a 'project' comprised of a large number of 'activities' which are arranged as the arcs in a complex acyclic network (see e.g. Figure 1). The activities at any network node 'commence' as soon as all activities 'terminating' at that node are completed. The time required to complete an activity once it can be begun is a random variable, and hence the time needed to complete the entire project is also a random variable.

In Technical Report No. 48 "Statistical Critical Path Analysis in Acyclic Networks: Statistical PERT" a comprehensive new procedure for obtaining information on the project completion time and its distribution was described and illustrated. That procedure involved the following five general steps:

#### Step 1: Identification

Represent the project and its component activities in terms of an acyclic network with one source and one sink. Identify each activity's completion time distribution or at least two points on each activity's completion time distribution.

#### Step 2: Simplification

Replace various activity configurations and their associated completion time distributions by a single equivalent activity and completion time distribution.

## Step 3: Decomposition

Decompose the simplified network into several subnetworks by separating parallel subnetworks and then separating the resulting subnetworks at each cut vertex. A cut vertex is any node such that every path from the source to the sink passes through it.

## Step 4: Analysis

Each subnetwork arising from Step 3 is analyzed on the basis of two points from each component activity's completion time distribution. The result of this analysis is an approximation of each subnetwork's completion time distribution and the moments of this distribution.

### Step 5: Synthesis

Combine the approximate subnetwork completion time distributions determined in Step 4. The result is an approximate completion time distribution for the entire project.

The purpose of this report is to document several refinements in the subnetwork analysis step, Step 4.

## 1. Analysis of a Subnetwork

The analytical procedure described in this section yields the following information on each subnetwork when each component activity's completion time distribution is replaced by a discrete two-point distribution:

- (a) Upper and lower bounds on the mean subnetwork completion time as well as the other moments of the subnetwork completion time.
- (b) Upper and lower bounds on the distribution function of the subnetwork completion time.

(c) An approximate distribution function of the subnetwork completion time.

Each subnetwork is assumed to be an acyclic network with one source, one sink, and no cut vertices.

The analysis of each subnetwork involves essentially two parts:

- The formation of "clusters" of activities whose effect on the subnetwork completion time seems to be interrelated.
- The approximation of the subnetwork completion time moments and distribution on the basis of the clusters.

## 1.1 Formation of Clusters

The actual completion time distribution of each individual activity, A, in the subnetwork is replaced by a discrete distribution with probability P at the lower point,  $\ell_A$ , and Q = 1-P at the upper point,  $u_A$ .

Let n be the number of activities in the subnetwork. Then for each of the 2<sup>n</sup> combinations of the L<sub>A</sub>'s and u<sub>A</sub>'s there will be a subnetwork completion time (a critical path time). The r-th moment of these 2<sup>n</sup> times will be denoted by T<sub>r</sub>, and the distribution function of these times will be denoted by F. The approximation of the T<sub>r</sub>'s (especially T<sub>1</sub>, the mean) and F is the goal of the subnetwork analysis. Since n will usually be fairly large, the complete enumeration of the 2<sup>n</sup> critical path times will usually be unreasonable. Hence the activities which are most likely to be on the critical path through the subnetwork are identified and their joint behavior investigated.

The mean of the completion time distribution for activity A is defined to be  $m_A = Pt_A + Qu_A$ . The standard deviation of the completion time distribution for activity A is defined to be  $s_A = \sqrt{Pt_A^2 + Qu_A^2 - m_A^2}$ 

and is assumed to be positive. (The assumption that  $s_A > 0$  is not really a practical restriction since the difference between a fixed activity completion time and one with a very small dispersion is negligible from a practical viewpoint.) The subnetwork's critical path when each activity's completion time is set equal to its mean will be referred to as the "original" critical path. The activities on this critical path will be referred to as "critical activities" with K equalling the number of such activities. Some non-critical activities might become critical if some of the completion times for the original critical activities were decreased. These activities are identified as follows. The completion time for one critical activity, say A, is set equal to  $\max\{m_A - \lambda s_A, 0\}$ where  $\lambda$  is a non-negative algorithm parameter which the user specifies. All other completion times are set equal to their means. Then the longest path through the resulting network is determined. Any activities on this path which were not on the original critical path are now referred to as the "associates" of A since the effect of these "associates" on the networks' completion time is related to A's completion time. This procedure is repeated for each original critical activity.

Each critical activity and its associates make up one "cluster".

These K initial clusters are now "pooled" by combining any two clusters with at least one activity in common. In general there will still be more than one cluster, and many of the n - K non-critical activities will not occur in any cluster.

The associates correspond to the activities which become critical when the completion times of the original critical activities are lowered. However, some of the originally non-critical activities may also become critical if their completion times exceed their means

and the completion times of the original critical activities are at their means. These activities are identified next. Each originally non-critical activity is investigated separately. If activity A is being investigated, then the completion time for A is set equal to  $\mathbf{m}_{\mathbf{A}}$  +  $\theta \mathbf{s}_{\mathbf{A}}$  where  $\theta$  is a non-negative algorithm parameter which the user specifies. The completion times for all other activities are set equal to their means, and the corresponding critical path determined. This critical path will either be the original critical path or a new path which includes A. In the latter case, the activities on the original critical path which are not on a new critical path containing A are called the "eliminants" of A. Thus, the effect of A's eliminants on the networks completion time is related to the completion time for A. Hence, A is added to any cluster which contains at least one of A's eliminants. After this procedure has been repeated for each originally non-critical activity, the resultant clusters are "pooled" again by combining any two clusters with at least one activity in common.

Although the number of clusters is reduced when the pooling on the basis of the associates occurs and then further reduced when the pooling on the basis of the eliminants occurs, there will generally remain more than one cluster and several activities not in any cluster.

In general the larger the values of  $\lambda$  and  $\theta$  the greater the number of activities in the clusters and the smaller the number of clusters. In particular the procedure for forming the clusters has the following properties:

Property 1: If  $\lambda_2 > \lambda_1$ , then any activity which would be an associate of a critical activity A when  $\lambda = \lambda_1$  would also be an associate of A when  $\lambda = \lambda_2$ .

- Property 2: If  $\theta_2 > \theta_1$ , then any critical activity which would be an eliminant of a non-critical activity A when  $\theta = \theta_1$  would also be an eliminant of A when  $\theta = \theta_2$ .
- Property 3: For any originally non-critical activity A there exists  $\theta_A$  such that A will have some eliminants for any  $\theta \geq \theta_A$ .
- Property 4: For any fixed value of  $\lambda$ , the set of activities in the union of the clusters is monotically non-decreasing as  $\theta \to \infty$ .
- Property 5: There exists a finite value  $\theta^*$  such that if  $\theta \ge \theta^*$ , then every activity would be in some cluster.
- Property 6: The number of clusters, originally K, is non-increasing as  $\theta \rightarrow \infty$ .
- Property 7: There exists a finite value  $\theta*$  such that if  $\theta \ge \theta*$ , then there would only be one cluster.

Most of the properties of the cluster formation procedure are fairly straightforward; however, Property 7 requires some special justification. This justification is based on the following definition and theorem which is proven in Appendix A.

<u>Definition</u>: In any acyclic network a <u>bridge</u> over any two consecutive arcs  $A_1$  and  $A_2$  is any arc  $A_3$  such that <u>all</u> paths from the source to the sink passing through  $A_3$  do not pass through either  $A_1$  or  $A_2$ .

Theorem 1: In any acyclic network with no cut vertices there is at least one bridge for any pair of consecutive arcs.

Property 3 implies that all activities will belong to some cluster if  $\theta \ge \theta^*$  and

 $\theta^* = \max\{\theta_A: A \text{ originally non-critical}\}.$ 

Now consider any two consecutive activities  $A_1$  and  $A_2$  on the original critical path. Theorem 1 implies that there is a bridge over  $A_1$  and  $A_2$ , say  $A_3$ . Since the original critical path passes through  $A_1$  and  $A_2$ ,  $A_3$  cannot be on the original critical path. Therefore, if  $\theta \geq \theta^* \geq \theta_{A_3}$ ,  $A_1$  and  $A_2$  will be eliminants of  $A_3$  and hence will be in the same cluster as  $A_3$ . Thus, since each cluster contains at least one original critical activity and any two consecutive original critical path activities belong to the same cluster when  $\theta \geq \theta^2$ , there is only one cluster when  $\theta \geq \theta^*$  and Property 7 is established.

## 1.2 Approximate Subnetwork Completion Time Moments and Distribution

## 1.2.1 A Lower Bound on T and an Upper Bound on F

For each cluster C let  $n_c$  denote the number of activities in C, and let  $v = 1, ..., 2^{n_c}$  index the  $2^{n_c}$  configurations of activity completion times when

- (a) the completion time for each activity A not in C is equal to its lower point,  $\ell_{\rm A}$ , and
- (b) the completion times for the activities in C are at each of the 2  $^{\rm c}$  possible combinations of their upper and lower points.

Let

 $t_v$  = critical path time for the v-th configuration

and

$$P_v = \text{probability of the v-th configuration}$$

$$= \prod_{i=1}^{n} [P_i(1 - \delta_{v,i}) + Q_i \delta_{v,i}]$$

where

- $\delta_{v,i} = 1$  if the time for the i-th activity in C is  $u_i$  in the v-th configuration
  - = 0 if the time for the i-th activity in C is  $\ell_i$  in the v-th configuration.

Then

$$\hat{T}_{r}^{-}(C) \equiv \sum_{v=1}^{n} p_{v} t_{v}^{r}$$

and

$$\hat{\mathbf{F}}^{+}(\mathbf{t}; C) = \sum_{\mathbf{v}=1}^{n} \mathbf{p}_{\mathbf{v}} \mathbf{I}_{\mathbf{t}}(\mathbf{t}_{\mathbf{v}})$$

where

$$I_t(t_v) = 1$$
 if  $t_v \le t$   
= 0 if  $t_v > t$ 

are the r-th moment of the  $2^{n_{c}}$  critical path times and their distribution function respectively. Let

$$T_r^-(\theta, \lambda) = \max_{C} \hat{T}_r^-(C)$$

and

$$F^+(t; \theta, \lambda) = \min_{C} \hat{F}^+(t; C)$$

which depend on  $\theta$  and  $\lambda$  since the composition and number of clusters depend on  $\theta$  and  $\lambda$ .

The first step in showing that  $T_r(\theta, \lambda)$  is a lower bound for  $T_r$  is proving the following theorem:

Theorem 2: For any cluster C, any positive integer r, and any activity A not in C,

$$\hat{T}_r(C \cup \{A\}) \geq \hat{T}_r(C)$$
.

<u>Proof:</u> Consider any <u>particular</u> critical path for a <u>particular</u> one of n the 2 combinations of upper and lower points involved in  $\hat{T}_r(C)$ . Consider the following two cases:

- (i) activity A with its completion time equal to  $\ell_A$  is on the critical path, and
- (ii) activity A with its completion time equal to  ${}^{l}_{A}$  is not on the critical path.

Let  $\delta_A = (u_A - \ell_A)$  and the particular critical path time be t. Then in case (i)

- (a) if the completion time for A is set equal to  $u_A$ , this will increase the r-th moment of the critical path time by  $Q[(t+\delta_A)^T-t^T]; \text{ and }$
- (b) if the completion time for A is set equal to  $\ell_A$ , this will not alter the r-th moment of the critical path time.

In case (ii)

- (a) if the completion time for A is set equal to  $u_A$ , this may increase the r-th moment of the critical path time by  $Q[(t+\delta_A)^T-t^T] \text{ or less, and}$
- (b) if the completion time for A is set equal to  $\ell_A$ , this will not alter the r-th moment of the critical path time.

Therefore in either case the contribution to  $\hat{T}_r(C \cup \{A\}) - \hat{T}_r(C)$  for this particular critical path will be between 0 and  $Q[(t + \delta_A)^r - t^r]$ . Since the contribution is non-negative for each particular combination,

$$\hat{T}_{r}(C \cup \{A\}) \geq \hat{T}_{r}(C)$$
. QED

A straightforward application of Theorem 2 yields the following theorem:

Theorem 3: For any two clusters  $C_1$  and  $C_2$  and any positive integer r,

$$\hat{T}_r(C_1 \cup C_2) \ge \max{\{\hat{T}_r(C_1), \hat{T}_r(C_2)\}}.$$

Property 2 of the cluster formation procedure implies that if  $\theta$  is increased the clusters expand or are pooled. Thus, Theorems 2 and 3 imply that, for fixed  $\lambda$ ,  $T_r^-(\theta, \lambda)$  is non-decreasing as  $\theta$  increases. Furthermore, Properties 5 and 7 together imply that for  $\theta$  sufficiently large there is only one cluster and all of subnetwork activities are in that cluster. Hence, for  $\theta$  sufficiently large  $T_r^-(\theta, \lambda) = T_r$ , and the following theorem is true:

### Theorem 4:

- (a)  $T_r^-(\theta, \lambda)$  is a non-decreasing function of  $\theta$  for any fixed values of  $\lambda$  and r;
- (b) there exists a finite value  $\theta^*$  such that  $\theta \ge \theta^*$  implies

$$T_r(\theta, \lambda) = T_r$$

for any  $\lambda$ , and r; and

(c) for any  $\theta$ ,  $\lambda$ , and r

$$T_r(\theta, \lambda) \leq T_r$$

Similarly, the first step in showing that  $F^{\dagger}(t; \theta, \lambda)$  is an upper bound on F(t) is the following theorem:

Theorem 5: For any cluster C, any value of t, and any activity A not in C,

$$\hat{F}^{\dagger}(t; C \cup \{A\}) \leq \hat{F}^{\dagger}(t; C).$$

Proof: Consider any particular configuration of activity times used to determine F<sup>+</sup>(t; C) before C is augmented by A. When A is added to C, this particular configuration will appear once with A at its upper percentile and once with A at its lower percentile. When A is at its lower percentile, the configuration's critical path time is unchanged. However, when A is at its upper percentile, the configurations' critical path time is either unchanged or possibly increased if A were on the configuration's critical path. Thus, the addition of A leaves the cumulative probability associated with critical path times less than or equal to t either unchanged or decreased.

A straightforward extension of Theorem 5 is the following theorem:

Theorem 6: For any two clusters C1 and C2 and any t,

$$\hat{F}^{\dagger}(t; C_1 \cup C_2) \leq \min{\{\hat{F}^{\dagger}(t; C_1), \hat{F}^{\dagger}(t; C_2)\}}.$$

Since Property 2 of the cluster formation procedure implies that the clusters expand or are pooled if  $\theta$  is increased, Theorem 5 and Theorem 6 together imply that, for all t and any fixed  $\lambda$ ,  $F^+(t; \theta, \lambda)$  is non-increasing function of  $\theta$ . Furthermore, Properties 5 and 7 together imply that for  $\theta$  sufficiently large there is only one cluster and all of the subnetwork activities are in that cluster. Hence, for  $\theta$  sufficiently large  $F^+(t; \theta, \lambda) = F(t)$  and the following theorem is true:

#### Theorem 7:

(a)  $F^{\dagger}(t; \theta, \lambda)$  is a non-increasing function of  $\theta$  for every t and any  $\lambda$ ;

(b) there exists a finite value  $\theta^*$  such that  $\theta > \theta^*$  implies

$$F^+(t; \theta, \lambda) = F(t)$$

for every t and  $\lambda$ ; and

(c) for any  $\theta$ ,  $\lambda$ , and t

$$F^+(t; \theta, \lambda) > F(t)$$
.

## 1.2.2 An Upper Bound on $T_r$ and a Lower Bound on F

For each cluster C let  $n_c$  denote the number of activities in C, and let  $v = 1, \ldots, 2^{n_c}$  index the  $2^{n_c}$  configurations of activity completion times when

- (a) the completion time for each activity not in the cluster is equal to its upper point, and
- (b) the completion times for the activities in the cluster are at each of the 2 c possible combinations of their upper and lower percentiles.

Let  $t_v$ ,  $p_v$ , and  $I_t(t_v)$  be as before and define

$$\hat{T}_{r}^{+}(C) = \sum_{v=1}^{n} p_{v} t_{v}^{r},$$

$$T_r^+(\theta, \lambda) = \min_C \hat{T}_r^+(C)$$

$$\hat{F}(t; C) = \sum_{v=1}^{n} p_{v} I_{t}(t_{v}),$$

and

$$F^-(t; \theta, \lambda) = \max_{C} \hat{F}^-(t; C).$$

Then an argument completely analogous to that used to prove Theorem 4 and Theorem 7 leads to the following theorems:

## Theorem 8:

- (a)  $T_r^{\dagger}(\theta, \lambda)$  is a non-increasing function of  $\theta$  for any fixed values of  $\lambda$  and r;
- (b) there exists a finite value  $\theta^*$  such that  $\theta \geq \theta^*$  implies

$$T_r^+(\theta, \lambda) = T_r$$

for any  $\lambda$  and r; and

(c) for any  $\theta$ ,  $\lambda$ , and r

$$T_r \leq T_r^+(\theta, \lambda)$$
.

#### Theorem 9:

(a) There exists a finite value  $\theta^*$  such that  $\theta \ge \theta^*$  implies

$$F^-(t; \theta, \lambda) = F(t)$$

for every t and any  $\lambda$ ; and

(b) for any  $\theta$ ,  $\lambda$ , and t

$$F(t; \theta, \lambda) < F(t)$$
.

## 1.2.3 Summary

Theorems 2-9 together imply that for any value of  $\theta$  and  $\lambda$  chosen by the algorithm user:

- (a)  $T_r(\theta, \lambda) \leq T_r \leq T_r(\theta, \lambda)$ , for any positive integer r; and
- (b)  $F(t; \theta, \lambda) \leq F(t) \leq F(t; \theta, \lambda)$  for any t.

They also imply that, for any r,  $\lambda$ , and t,

$$T_r^+(\theta, \lambda) - T_r^-(\theta, \lambda)$$

and

$$F^+(t; \theta, \lambda) - F^-(t; \theta, \lambda)$$

would decrease monotonically to zero if  $\theta$  were increased. In fact, Theorems 2-9 imply that there exists a value  $\theta^*$  which doesn't depend on r,  $\lambda$ , or t such that  $\theta \geq \theta^*$  implies that

$$T_r^-(\theta, \lambda) = T_r = T_r^+(\theta, \lambda)$$

and

$$F^-(t; \theta, \lambda) = F(t) = F^+(t; \theta, \lambda).$$

A reasonable approximation for F(t) is

$$\hat{F}(t; \theta, \lambda) = \frac{1}{2} [F(t; \theta, \lambda) + F(t; \theta, \lambda)].$$

## 2. Comparison with the Original Subnetwork Analysis Procedure

The original subnetwork analysis procedure documented in Technical Report No. 48 formed the clusters in essentially the same way as the new subnetwork analysis procedure described in this report except that in the original procedure P always equalled  $\frac{1}{3}$  and  $\theta$  and  $\lambda$  multiplied the point difference,  $u_A - t_A$ , instead of the standard deviation,  $\sqrt{Pt_A^2 + Qu_A^2 - m_A^2}$ .

In the original procedure  $n_{ij} = \sum_{c} n_{c}$  denotes the number of activities in the union of the clusters, and  $T_{r}^{+}(\theta, \lambda)$  is defined to be the average of the r-th power of the 2 critical path times when

(a) the completion time for each activity not in the union of the clusters is equal to its upper point, and (b) the completion times for the activities in the union of the clusters are at each of the 2 possible combinations of their upper and lower points.

Correspondingly,  $F^-(t; \theta, \lambda)$  was defined to be the proportion of these  $2^{n}$  critical path times that were less than or equal to t. Analogously,  $F^+(t; \theta, \lambda)$  was the proportion of the  $2^{n}$  critical path times less than or equal to t when

- (a) the completion time for each activity not in the union of the clusters is equal to its lower point, and
- (b) the completion times for the activities in the union of the clusters are at each of the  $2^{n_{\bigcup}}$  possible combinations of their upper and lower points.

The only problem with this procedure is that  $2^{n_U}$  may be quite large even for relatively small values of  $(\theta, \lambda)$ . For example, if the original critical path contains 10 activities and each critical activity has one associate, then  $2^{n_U} = 2^{20} = 1,048,576$ , and the determination of  $T_r^+(\theta, \lambda)$ ,  $F^-(t; \theta, \lambda)$ , and  $F^+(t; \theta, \lambda)$  requires the evaluation of over 2 million critical path times. On the other hand, in the new procedure the determination of  $T_r^-(\theta, \lambda)$ ,  $T_r^+(\theta, \lambda)$ ,  $F^-(t; \theta, \lambda)$ ,  $F^+(t; \theta, \lambda)$  requires the evaluation of only  $2 \sum_{c} 2^{c}$  critical path times, 80 in the example. Thus the new procedure greatly reduces the computational effort required to bound the project completion time moments and distribution.

A practical alternative to evaluating all 2 critical path times called for in the original procedure is to randomly sample the 2 critical path times when n<sub>U</sub> is large and base the bounds on the sample critical path times. A computer program for the original procedure with a sampling option is documented in Appendix C. (This program supercedes

the subnetwork analysis program given in Technical Report No. 48.) It should be noted that the original subnetwork analysis procedure with the sampling option in effect is still superior to a simple Monte Carlo simulation of the subnetwork since the subnetwork analysis procedure

- (i) provides the information in terms of associates and eliminants about which activities play an important role in determining the subnetwork's completion time and the interactions among activities, and
- (ii) samples only those activities which most influence the subnetwork completion time,

Furthermore, the loss in accuracy due to sampling in the subnetwork analysis procedure seems to be quite minimal even for relatively small sample sizes - see for example Table 2 and Table 3.

All specific computational results documented in this report are for the project network given in Figure 1. (This network is the simplified network from a large naval PERT problem.) A listing of each activity's two-point approximation except for its P and Q is given in Table 1.

Sampling can also be used in the new subnetwork analysis procedure in the somewhat unlikely event that  $\theta$  and  $\lambda$  are chosen so large that  $2^n c$  for some cluster C is too large. In this case the probability that the v-th configuration of activity completion times  $v=1,\ldots,2^n c$  is selected on a sampling trial is

$$P_{v} = \prod_{i=1}^{n} [P_{i}(1 - \delta_{v,i}) + Q_{i}\delta_{v,i}]$$

where

Table 1. The Upper and Lower Points in the Two-Point Approximations to the Activity Completion Time Distributions for the Project Network in Figure 1

Activity	Origin	Terminal	Lower	Upper
Number	Node	Node	Point	Point
1	1	2	0.0	0.0
2	8	12	336.27	429.47
3	2	3	57.47	89.96
4	2	4	57.47	89.96
5	2	5	57.47	89.96
6	2	6	57.47	89.96
7	2	7	57.47	89.96
8	3	8	68.96	107.95
9	4	8	68.96	107.95
10	5	8	68.96	107.95
11	6	8	68.96	107.95
12	7	8	68.96	107.95
13	2	8	150.36	193.49
14	6	10	333.96	403.85
15	3	9	333.96	403.85
16	7	11	355.10	409.85
17	11	18	141.75	221.90
18 19	10 9	13 14	672.36 560.89	783.11 660.00
20	9	15	560.89	660.00
21	9	16	560.89	660.00
22	11	17	542.80	638.71
23	12	18	111.10	173.92
24	18	19	256.03	346.98
25	12	19	302.80	400.67
26	12	20	311.95	410.71
27	11	21	423.58	530.74
28	12	22	315.35	415.71
29	19	20	7.66	11.99
30	20	21	16.77	22.55
31	21	22	11.49	17.99
32	22	23	39.54	48.87
33	12	26	301.91	400.86
34	5	26	767.09	892.74
35	12	27 .	350.31	460.06
36	12	24	382.32	464.98
37	12	25	385.28	461.54
38	25	24	11.49	17.99
39	24	23	16.28	23.00
40	26	27	7.66	11.99
41	27	25	20.86	28.29
42	4	28	810.17	976.10
43	23	29	15.32	23.99

Activity Number	Origin Node	Terminal Node	Lower Point	Upper Point
44	28	30	15.32	23.99
45	14	31	57.47	89.96
46	16	31	49.81	77.96
47	15	31	53.64	83.96
48	17	31	88.12	137.94
49	31	32	3.83	6.00
50	32	13	49.81	77.96
51	13	33	109.01	152.63
52	11	32	745.50	811.32
53	10	32	714.74	799.83
54	30	14	0.0	0.0
55	30	16	0.0	0.0
56	30	15	0.0	0.0
57	29	17	0.0	0.0
58	29	28	0.0	0.0

Table 2. The Effect of Sampling in the Original Subnetwork Analysis
Procedure: Percentiles of the Project Completion Time Distribution

Percentiles	Sample Sizes						
	$(\theta,\lambda) = (0,0)$		$(\theta,\lambda) = (.25,0)$		)		
	2 <sup>n</sup> U = 2 <sup>6</sup>	2 <sup>5</sup> 2 <sup>4</sup>	2 <sup>n</sup> U = 2 <sup>11</sup>	1000	500	200	100
.05	1360	1363 1377	1381	1381	1381	1384	1384
.10	1383	1390 1413	1409	1406	1411	1406	1414
.15	1403	1413 1423	1424	1421	1429	1424	1423
.20	1416	1423 1436	1441	1436	1443	1441	1446
.25	1430	1430 1446	1451	1448	1451	1451	1453
.30	1446	1453 1466	1458	1456	1461	1458	1463
.35	1459	1479 1472	1468	1466	1471	1468	1471
.40	1476	1486 1476	1478	1473	1478	1476	1478
.45	1499	1499 1512	1483	1483	1483	1483	1483
.50	1542	1542 1516	1488	1486	1491	1491	1488
.55	1578	1578 1575	1496	1496	1498	1498	1498
.60	1578	1578 1575	1501	1501	1505	1501	1503
.65	1602	1602 1579	1513	1510	1513	1513	1513
.70	1605	1605 1602	1515	1515	1515	1523	1515
.75	1605	1618 1605	1525	1525	1525	1528	1525
.80	1621	1618 1605	1533	1533	1530	1538	1530
.85	1622	1622 1618	1543	1543	1543	1545	1543
.90	1645	1622 1622	1558	1558	1558	1570	1577
.95	1648	1645 1648	1585	1585	1582	1587	1597
.975	1648	1648 1648	1607	1607	1605	1605	1622
.99	1648	1648 1648	1625	1625	1625	1622	1647
1.00	1648	1648 1648	1649	1649	1649	1649	1649

Table 3. The Effect of Skewed Activity Completion Time
Distributions on the Subnetwork Analysis Procedures.

# Estimated Percentiles of the Project Completion Time Distribution

		Original Subnetwork Analysis Procedure		New Subnetwork Analysis Procedure		
	Monte	(Sample		(Sample Size = 1000/cluster)		
Percentile	Carlo	= 1000/c	luster)			
		lst Run	2nd Run	lst Run	2nd Run	
.05	1405	1402	1396	1370	1374	
.10	1423	1416	1416	1390	1398	
.15	1435	1430	1433	1402	1410	
.20	1447	1438	1443	1425	1437	
. 25	1457	1448	1449	1437	1449	
.30	1467	1453	1456	1450	1453	
.35	1477	1462	1466	1461	1461	
.40	1486	1469	1473	1484	1500	
. 45	1496	1476	1479	1504	1524	
.50	1507	1481	1483	1528	1528	
.55	1516	1487	1489	1528	1528	
.60	1527	1495	1496	1528	1528	
.65	1538	1500	1499	1563	1560	
.70	1549	1510	1512	1567	1567	
.75	1560	1517	1516	1579	1579	
.80	1580	1526	1529	1587	1587	
.85	1603	1541	1542	1598	1602	
.90	1627	1550	1552	1610	1614	
.95	1675	1575	1582	1622	1673	
1.00	2019	1646	1648	1720	1720	

<sup>\*</sup>The "lst run" and "2nd run" correspond to two different samples with different initializations of the random number generator.

 $\delta_{v,i}$  = 1 if the time for the i-th activity in C is  $u_i$  in the v-th configuration

= 0 if the time for the i-th activity in C is l<sub>i</sub> in the v-th configuration.

Then with I, (t,) as before the estimated bounds from C are

$$\hat{T}_{r}^{-}(C) = \frac{2^{n_{c}}}{N} \sum_{v=1}^{n_{c}} w_{v} p_{v} t_{v}^{r}$$

and

$$\hat{F}^{+}(t; C) = \frac{\sum_{v=1}^{n} \sum_{v=1}^{n} w_{v} p_{v} I_{t}(t_{v})}{\sum_{v=1}^{n} \sum_{v=1}^{n} w_{v} p_{v} I_{t}(t_{v})}$$

where  $w_V$  is the number of times the v-th configuration appears in the sample, N is the sample size, and  $t_V$  is the critical path time corresponding to the v-th configuration of activity completion times with the completion time for each activity A not in C equal to  $\ell_A$ . Similar modifications are made for  $T_r^+(C)$  and  $F^-(t; C)$ . The corresponding estimators  $T_r^-(\theta, \lambda)$ ,  $T_r^+(\theta, \lambda)$ ,  $F^-(t; \theta, \lambda)$ , and  $F^+(t; \theta, \lambda)$  are all unbiased.

A computer implementation of the new subnetwork analysis procedure including the sampling option is documented in Appendix B. In addition to reducing the computational effort, the new subnetwork analysis procedure allows the user to specify any probabilities (P, Q) for (L, u) instead of requiring (1/2, 1/2). This would not be of great significance if all activity completion time distributions were symmetric. However, since many completion time distributions are skewed, the ability to specify (P, Q) can be a real advantage. To exemplify this advantage, the completion time for each activity in Figure 1 was taken to be a linearly

transformed chi-square random variable,  $(\chi_3^2 - c_1)/c_2$ , where  $c_1$  and  $c_2$  were determined so that the points in Table 1 corresponded to the 15-th and 85-th percentiles respectively. This made the activity's completion time distribution highly skewed. Then the corresponding project completion time distribution was approximated using

- (i) a Monte Carlo simulation of size 1000,
- (ii) the new subnetwork analysis procedure with (P, Q) = (1/2, 1/2) for all activities, and
- (iii) the new procedure with each activity's (P, Q) chosen so that the mode and first two moments of its two-point approximation equalled the mode and first two moments of its transformed chi-square distribution.

The results are given in Table 3. If the Monte Carlo approximation is used as a basis for comparison, the value of being able to specify (P, Q) is obvious.

The Monte Carlo PERT simulation program used in the above experiment is documented in Appendix D and supercedes the Monte Carlo PERT program given in Technical Report No. 48.

In the special case where every activity's (P, Q) is (1/2, 1/2), the  $\hat{T}_r^-(C)$  and  $\hat{F}^+(t; C)$  can be computed on the basis of the  $2^{c}$  critical path times corresponding to

- (a) the completion time for each activity A not in C being equal to the mean,  $m_{_{\rm A}}$ , and
- (b) the completion times for the activities in C being at each of the 2 c possible combinations of their upper and lower points.

This is a change from the usual computation in that the activities not in C are at their means here instead of their lower points. This change

will tend to improve the estimators  $T_r^-(\theta, \lambda)$  and  $F^+(t; \theta, \lambda)$ . However, this change is only guaranteed not to invalidate Theorems 4 and 7 when all (P, Q) are (1/2, 1/2). The computer implementation of the new subnetwork analysis procedure includes the option to make this change.

## Conclusion

The new subnetwork analysis procedure

- forms associates, eliminants, and clusters in essentially the same way as the original procedure,
- (ii) bounds the project's completion time moments and distribution primarily on the basis of the individual clusters instead of on a pooled cluster, and
- (iii) approximates an activity's completion time distribution by
  a two-point distribution with possibly unequal probabilities
  for the two points instead of always equal probabilities.

The advantage of (ii) is that much much fewer critical path times need to be evaluated in determining the bounds on the project completion time. The advantage to (iii) is the ability to better approximate skewed activity completion time distributions.

Computer implementations of the new subnetwork analysis procedure, the original subnetwork analysis procedure, and a Monte Carlo simulation algorithm are documented in Appendices B, C, and D respectively. Both subnetwork analysis procedures include options to use sampling for large clusters.

### References

Sielken, R. L. Jr., L. J. Ringer, H. O. Hartley, and E. Arseven,
"Statistical Critical Path Analysis in Acyclic Stochastic
Networks: Statistical PERT," Institute of Statistics, Texas
A&M University Project Themis Technical Report No. 48,
November 1974.

#### APPENDIX A

#### Proof of Theorem 1

The principle objective of this appendix is to prove the following theorem:

Theorem 1: In any acyclic network with no cut vertices there is at least one bridge for any pair of consecutive arcs.

The networks considered in this appendix are assumed to be acyclic, have no cut vertices, and have one source and one sink. Also the two arcs  $A_1$  and  $A_2$  are any two adjacent (consecutive) arcs with  $A_1$  preceding  $A_2$ .

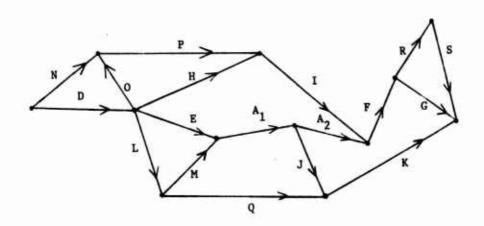
<u>Definition 1</u>: A <u>bridge</u> over  $A_1$  and  $A_2$  is any arc, say  $A_3$ , such that <u>all</u> paths from the source to the sink passing through  $A_3$  do not pass through either  $A_1$  or  $A_2$ .

<u>Definition 2</u>: An <u>origin violator</u> of  $A_1$  and  $A_2$  is an arc, say  $A_3$ , such that there exists a path from the terminal node of  $A_1$  to the sink which passes through  $A_3$ .

Definition 3. A terminal violator of  $A_1$  and  $A_2$  is an arc, say  $A_3$ , such that there exists a path from the source to the terminal node of  $A_1$  which passes through  $A_3$ .

An intuitive feeling for these definitions can be obtained by considering any path  $P^*$  from the source to the sink which passes through  $A_1$  and  $A_2$ . If an arc  $A_3$  is an origin violator, then there is a path from the source to the sink which follows along  $P^*$  through the terminal

node of  $A_1$  and then goes through  $A_3$ . This path "originates" from P\* too late for  $A_3$  to be a bridge over  $A_1$  and  $A_2$ . Similarly, if  $A_3$  is a terminal violator, then there is a path from the source to the sink which passes through  $A_3$  and then joins into P\* before P\* passes through the terminal node of  $A_1$ . This path "terminates" into P\* too early for  $A_3$  to be a bridge.



BRIDGES over  $A_1$  and  $A_2$ : H, I, N, O, P, and Q ORIGIN VIOLATORS of  $A_1$  and  $A_2$ :  $A_2$ , F, G, J, K, R, and S TERMINAL VIOLATORS of  $A_1$  and  $A_2$ :  $A_1$ , D, E, L, and M

The following three lemmas are straightforward consequences of the definitions of a bridge, an origin violator, and a terminal violator.

Lemma 1: Every branch in the network is either a bridge over  $A_1$  and  $A_2$ , an origin violator of  $A_1$  and  $A_2$ , or a terminal violator of  $A_1$  and  $A_2$ .

Proof of Lemma 1: Suppose that  $A_3$  is not a bridge. Then there exists a path P from the source to the sink which contains  $A_3$  and either  $A_1$  or  $A_2$ .

Suppose that P contains  $A_1$ . If  $A_3 = A_1$  or  $A_3$  precedes  $A_1$  on P, then P contains a path from the source to the terminal node of  $A_1$  which passes through  $A_3$ , and  $A_3$  would be a terminal violator. On the other hand, if  $A_3$  follows  $A_1$  on P, then P contains a path from the terminal node of  $A_1$  to the sink which passes through  $A_3$ , and  $A_3$  would be an origin violator.

Suppose that P contains  $A_2$ . If  $A_3 = A_2$  or  $A_3$  comes after  $A_2$  on P, then P contains a path from the terminal node of  $A_1$  (the origin node of  $A_2$ ) to the sink which passes through  $A_3$ , and  $A_3$  would be an origin violator. If  $A_3$  comes before  $A_2$  on P, then P contains a path from the source to the terminal node of  $A_1$  (the origin node of  $A_2$ ) which passes through  $A_3$ , and  $A_3$  would be a terminal violator. This completes the proof of Lemma 1.

Lemma 2:  $A_1$  is a terminal violator of  $A_1$  and  $A_2$ , and  $A_2$  is an origin violator of  $A_1$  and  $A_2$ .

Lemma 3: Any arc  $A_3$  cannot be both an origin violator of  $A_1$  and  $A_2$  and a terminal violator of  $A_1$  and  $A_2$ .

Proof of Lemma 3: Suppose that an arc  $A_3$  is both an origin violator and a terminal violator. Since  $A_3$  is an origin violator, there exists a path from the terminal node of  $A_1$  to the origin node of  $A_3$ . Since  $A_3$  is a terminal violator, there exists a path from the terminal node of  $A_3$  to the terminal node of  $A_1$ . The existence of these two paths, however, implies the existence of a circuit which contradicts the given acyclic structure of the network. This completes the proof of Lemma 3.

Proof of Theorem 1: Since the terminal node of  $A_1$  cannot be a cut vertex, there exists a path P from the source to the sink which does not pass through the terminal node of  $A_1$ . Denote the arcs on P by  $C_1, C_2, \ldots, C_p$  with  $C_{i-1}$  preceding  $C_i$  on P.

Suppose that none of  $C_1$ ,  $C_2$ , ...,  $C_p$  are bridges over  $A_1$  and  $A_2$ . Then Lemma 1 and Lemma 3 together imply that each of  $C_1$ ,  $C_2$ , ...,  $C_p$  is either an origin violator of  $A_1$  and  $A_2$  or a terminal violator of  $A_1$  and  $A_2$  but not both. Since the origin node of  $C_1$  is the source,  $C_1$  cannot be an origin violator and must be a terminal violator. Similarly, since the terminal node of  $C_p$  is the sink,  $C_p$  cannot be a terminal violator and must be an origin violator. Hence, there exists  $j \geq 1$  such that  $C_1$ ,  $C_2$ , ...,  $C_j$  are all terminal violators and  $C_{j+1}$  is an origin violator.

Since  $C_j$  is a terminal violator, there exists a path from the terminal node of  $C_j$  to the terminal node of  $A_1$ . Furthermore, since  $C_{j+1}$  is an origin violator, there is a path from the terminal node of  $A_1$  to the origin node of  $C_{j+1}$  (the terminal node of  $C_j$ ). These two paths imply the existence of a circuit from the terminal node of

 $C_j$  to the terminal node of  $A_1$  and then back to the terminal node of  $C_j$ . (The definition of P implies that the terminal node of  $C_j$  is not the terminal node of  $A_1$ .) This contradicts the given acyclic structure of the network and completes the proof of Theorem 1.

#### APPENDIX B

#### New Subnetwork Analysis Program

The New Subnetwork Analysis Program is an implementation of the analytical procedure described in Section 1 of this report. The basic required input is

- (a) an acyclic network with one source and one sink,
- (b) two points from each component activity's completion time distribution
- (c) probability P to be associated with the lower point, and
- (d) specified values for the algorithm parameters  $\boldsymbol{\theta}$  and  $\boldsymbol{\lambda}$  . The output is mainly
  - (a) upper and lower bounds on the moments of the network completion time,  $T_r^+(\Theta, \lambda)$  and  $T_r^-(\Theta, \lambda)$  r = 1, 2, ..., 10;
  - (b) upper and lower bounds on the distribution function of the network completion time,  $F^+(\cdot; \theta, \lambda)$  and  $F^-(\cdot; \theta, \lambda)$ ; and
  - (c) an approximate network completion time distribution,  $F(\cdot; \theta, \lambda) = \frac{1}{2} [F^{+}(\cdot; \theta, \lambda) + F^{-}(\cdot; \theta, \lambda)].$

The basic computational technique for determining critical path times is the Simplex Algorithm. This algorithm is applied to the dual problem. The Simplex Algorithm is used instead of the standard network analysis techniques because the Simplex Algorithm is ideally suited for the type of parametric programming required to evaluate several critical path times when only the activity times vary from one problem to the next.

A listing of the Subnetwork Analysis Program and a program flowchart are given at the end of this appendix.

# Specific Input Instructions:

- Card 1. Col. 1-3: The number of activities in the network, Format (I3).
  - Col. 4-6: The number of nodes in the network, Format (13).

# For each activity one card with:

- Col. 11-15: The origin node of the activity, Format (15).
- Col. 21-25: The terminal node of the activity, Format (I5).
- Col. 31-40: The lower point on the activity's completion time distribution, Format (F10.0).
- Col. 41-50: The upper point on the activity's completion time distribution, Format (F10.0).
- Col. 51-60: The probability P to be associated with the lower point (1-P will be associated with the upper point), Format (F10.5).
- Next Card. Col. 1: OPTON1. OPTON1=1 implies that the program will terminate after the clusters have been formed on the basis of associates and eliminants. OPTON=1 implies that the program will follow the normal procedure.
  - Col. 2: OPTON2-1 implies that the lower bounds on the moments of the project completion time and the upper bound on its distribution will be determined by using all activity times outside the cluster at their means instead of their lower points. This is only guaranteed to be a valid procedure when all (P, Q) = (1/2, 1/2). OPTON2#1 implies that the program will follow the normal procedure.

Next Card. Col. 1-3: IEDF. The program computes an absolute upper and lower bound for the network completion time. This range is subdivided into IEDF equal parts and the approximate distribution function (F<sup>+</sup>, F<sup>-</sup>, F̂) values are printed at each of these dividing points. IEDF would usually be between 10 and 100. IEDF, Format (I3).

Next Card. Col. 1-5:  $\theta$ , Format (F5.2).

Col.6-10:  $\lambda$ , Format (F5.2),

Next Card. Col.1-10: SAMSIZ. The number of activity time configurations to be randomly selected for explicit consideration in each cluster analysis.

If SAMSIZ < 0 or SAMSIZ > 2 c, all activity time configurations will be explicitly considered - no random sampling will be done. Format (I10).

The nodes should be numbered 1, 2, ..., n with the source being number 1, the sink being number n, and the other node numbers being arbitrary. The activities should be numbered 1, 2, ... in any order desired.

# Current Dimension Restrictions:

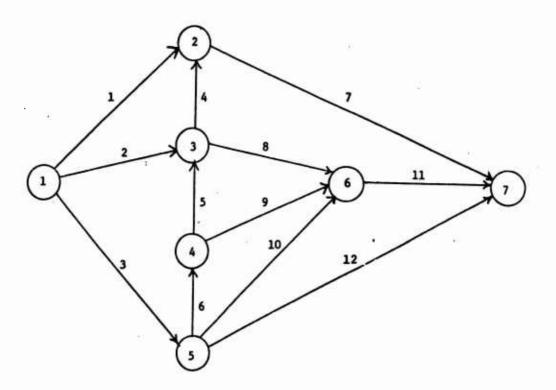
Currently the program is dimensioned for a maximum of

- 60 Activities
- 40 Nodes
- 25 Clusters
- 25 Activities/Cluster and IEDF < 100.

# Example:

The Program's input and output are illustrated in terms of the network in Figure B-1.

Figure B-1: New Subnetwork Analysis Program Example Network



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1	2	17.26	19.44	• 5
1	3	19.26	21.44	. 9
1	5	12.76	15.91	.3
3	2	3.51	4.01	. 8
4	3	:3.01	5.43	.75
5	•	3.52	4.25	• 5
2	7	13.75	14.48	.65
3	6	5.05	8.43	•1
4	6	5.36	6.51	.7
5	6	8.78	11.44	.55
6	7	15.76	17.21	• 9
5	7	14.32	18.35	• 9

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'n	•	m	3.0100	5-4300	1.6150	1.0479	0.7500
•	<b>V</b> C	•	3.5200	4.2560	3. 4850	0.3659	0.5900
^	~	^	13,7500	14.4960	14.0255	0.3482	0.6500
c	3	•	S.r503	6054.6	9.0920	1.0140	0.1000
0	•	9	5.3600	6.5100	5.7050	0.5270	0.700
2	r	•	8.7800	11.4400	9.0770	1.3233	0.5500
11	ç	_	15.7600	17.2100	16,0500	0.5300	0.800
12	r	^	14.3200	18.3500	14.7230	1.2090	0.00.0

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<sup>9.</sup> THE ACTIVITIES IN THE 3-TH CLUSTER ARE AS FOLLOWS:

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                                                                                                                                                                                                                                                                                                                                                                           C + 19440D 22
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     0 - 201 32D C2
                                                       7 AFTIVITIES MAY ON THE CUITICAL DATH. THEY AND AS FOLLOWS:
THE FLIMINANTS OF EACH NUN-CRITICAL-PATH ACTIVITY APE NOW DESCHAINTOR
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          4-TH ACTIVITY HAS REEN CHANGED TO
                                                                                                                                                                                                                                                                                                                                                                           1-TH ACTIVITY HAS BEEN CHANGED TO
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   THE COMPLETION TIME FOR THE 2-TH ACTIVITY HAS BEEN CHANGED TO
                                                                                                                                                                                                                                                                                                                                                                                                                            C FLIMINANTS COPRESPENDING TO ACTIVITY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     S ELIMINANTS CORPES CHOING TO ACTIVITY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          G ELIMINANTS CORRESPONDING TO ACTIVITY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          THE COMPLETION.TIME FOR THE
                                                                                                                                                                                                                                                                                                                                                                           THE COMPLETION TIME FOR THE
                                                                                                                                                                                                                                                                                                                                                                                                                              THERE ARE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           THERE ARE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               THERE ARE
                                                     THESE APP
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0.143540 62	
THE COMPLETION TIME FOR THE 7-TH ACTIVITY HAS BEEN CHANGED TO 0.14354D C2	THERE ARE O FLIMINANTS CORRESPONDING TO ACTIVITY 7
TWF COMPLETION TIME FOR THE	THERE ARE OFLIMINANT

D.	
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3F EN	ACTI
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ACTI	ESPO
H 1-6	. O ELIMINANIS CORRESPONDING TO ACTIVITY
L.	ANTS
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E .	) EL
1	w
7110	THERE ARE
THE CCMPLETICN TIME FOR THE 9-TH ACTIVITY HAS BEEN CHANGED TO	THER
THE	

C.623230 01

-11300D C2

THE CEMPLETION TIME FOR THE 12-TH ACTIVITY HAS HEEN CHANGED TO THERE ARE A FLIMINANTS CORRESPONDING TO ACTIVITY 12

C.159320 02

S CLUSTLPS. THEPE ARE 1-TH CLUSTER. THEY ARE AS FOLLOWS: 1 ACTIVITIES IN THE

1 CLUSTERS HAVE REEN POOLED TO MAKE THIS CLUSTER. THEY WERE AS FOLLOWS:

THEY ARE AS FOLLOWS: 2-TH CLUSTER. 1 ACTIVITIES IN THE THERE ARE 1 CLUSTERS MAVE BFEN POOLED TO MAKE THIS CLUSTEF. THEY WERE AS FOLLOWS:

THEY APE AS FOLLOWS: 3-TH CLUSTEP. 1 ACTIVITIES IN THE THERE ARE 1 CLUSTERS HAVE BEEN POOLED TO MAKE THIS CLUSTER. THEY WERE AS FOLLOWS:

1 CLLSTERS HAVE BEFN POCLED TO MAKF THIS CLUSTER. THFY WERF AS FOLLOWS: THEY APE AS FOLLCES: 4-TH CLUSTER.

1 ACTIVITIES IN THE

THERE ARE

THERE APP

5-TH CLUSTFP. THEY ARE AS FOLLINS: 1 ACTIVITIES IN THE 1 CLUSTERS MAVE BEEN POOLEC TO MAKE THIS CLUSTEP. THEY WERE AS FOLLOWS:

THE FOLLCWING TAPLES WERE DETERMINED CENSIDERING ALL ACTIVITY CENFIGURATIONS. THE INITIALIZATION DARAMETER FOR ANY SAMPLING IS IY =

# MANUAL TO THE PRODUCTION 0.186230 04 0-431420 92 0.8042AD 05 0.347520 07 0-15023D 09 0.645680 10 0.281080 12 0.12165D 14 0.526670 15 0.228090 17 Ħ Ħ Ħ #1 A LOWFD BOUND. T-(IC:THETA.LAMBDA), ON THE IC-TH MOMENT OF THE NETWORK COMPLETION TIME 9-TH MOMENT OF THE NETWORK COMPLETION TIME 1-TH MOMENT OF THE NETWORK COMPLETION TIME NETADAK COMPLETION TIME MOMENT OF THE NETWORK COMPLETION TIME MOMENT OF THE NETWORK COMPLETION TIME 8-TH MOMENT OF THE NETWORK COMPLETION TIME 2-TH MOMENT OF THE NETWORK COMPLETION TIME NETWOOK CCMPLETION TIME NETWORK COMPLETION TIME 4-TH MOMFNT OF THE 3-TH MOMENT OF THE S-TH MOMINT DE THE 6-TH 7-TH A LIMER MINING. T-( 1:THETA.LAMHDA), ON THE BCUND, T-( 3:THETA.LAMADA), ON THE A LOWER SOUND. T-( 4:THETA.LARBDA), ON THE A LCMER BOUND. T-( SITHETA.LAMBDA), ON THE A LOWER SCUND, T-( SITHETA, LAMBDA), ON THE A LIMER ADDING. T-( 9:THETA:LAMBDA). ON THE T-( 2:THFTA.LAMBDA). ON THE A LOWER GOUND. T-( SITHETA, LAMBDA), ON THE A LOWFR BCUND. T-( 7:THFTA.LAMADA). ON THE

A LOWFR ROUND.

A LCBER

		•	*																	
_	00	00	00	0	00	S	10	01	10	51	10	0.1	10	0.1	010	10	5	10	5	01
A : LAMBDA	0-10061-0	6.136660	0.10000	0-100000	C.100COD 00	C-100rcD	000001.0	C.13000	0-100000	0.103000	0.100000	0-100000	0.100000	0.100500	0-130000	0.100000	0.100000	G-12000D	0.100000	0.10000
THET																				
÷	-	"	-	-	-	-	-	-	H	11	#	"	-	-	11		-	-	-	11
	0	<del>ت</del>	E	5	5	5	C	5	C	5	113	5	5	ç.	5	5	2	5	7	3
ISTRIBUTION	0-100000 01	6.10.0000.013	G00001-0	C. 10000	0.1300cD	0.10000	0.10000	C- 10000D	C. 120000 C1	C-100000 013	0.116000	C-100000 C1)	C. 19rcob	r.10cc0D	0-100000	G. 15CO.D	C+10000	100000	C. 1009CD c1	C. 10000D
MED	510	:10	:10	: 10	: 10	01:	:10		:10		: 10	:10	: 10	:1:	: 10	: 10	:10	:10	. 10	110
BCUND ON THE NOTWURK COMPLETION TIME DISTRIBUTION: F+(.;THETA;LAMBDA	0.1000000 01;	0.100100	00000010	0.100000	0.100000	C-10000D	0.10000	0.10000	0.10000	0.136960	0.100300	0.10000	0.100rcp	9.160960	0-196669	C-10000D	0-100000	0.100000	C-100-CD	C-100C0D
Y K	62:	0.5	02:	02:	. 60	25	32:	. 20	62:	25	02:	05:	35	25	25	C5:	:25	80	2:	35
NETW	3.40£570 C2	0.412130	0.41770D	0-423260	1.424830	0-434390	C. 43996D	0-44552D	0-451090	2.456650	0.462210	0.467780	0-47334D	0.47891D	0-484470	3.490C4D	3.4955CD	0.501170	3.506730	0.51230D
THE	6	6	4.0	0	4.0	ċ	9	C	0		6	0	9.6			0.4	3	0	0	•
Ž																				
	F+(	1+4	F + C	F+ (	1+4	₩ +	F+ +	F + C	F+ (	) ÷ u	F+(	F + (	H + (	F+(	F+(	) ÷ u	F +	F+(	) + u	F.
AN UPPER																				
Z																				

TIME = 0.494150 02	TIME = 0.244290 C4	TIME = 0.120A3D 06	TIMF = 0.59789D C7	FIMF = 0.296CCD 09	TIME = 0.14661D 11	TIME = 0.72655D 12	TIME = 0.36023D 14	TIME = 0.17870D 16	11 ME # 0 -886940 17
K COMPLETION	K COMPLETTON	K COMPLETION	K COMPLETION	K COMPLETION .	K COMPLETION	K COMPLETIUN	K COMPLETION .	K COMPLETION	K COMPLETION
NETWOR	NETBOR	NETWOR	NETWOR	NETWOR	NET WOR	· NETWOR	NETWOR	E NET #OR	NETWOR
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MOMEN	NUMBER	MOMEN	MUMEN	NEWCOM	MOMEN	NUMER	MOMEN	MUMEN	MOMEN
1-1	2-TH	3-14	4-TH	S-TH	1 1 1 9	7-TH	8-TH	9-1H	19-TH
H	4 H	THE	4 H	1 HE	7 HE	T HF	THE	THE	THE
Č	Ö	<b>Z</b>	S	Ö	Š	Ž	ŏ	Ç	ŏ
AN UPPER RCUND. T+( 1;THFTA.LAMBDA), ON THE 1-TH MOMENT OF THE NETWORK COMFLETION TIME	AN UPPER BCUND. T+( 2:THETA.LAMBDA). ON THE 2-TH MOMENT OF THE NETWORK COMPLETION TIME	AN UPPER BOUND, T+( SITHETA.LAMEDA), ON THE 3-TH MOMENT OF THE NFTWORK COMPLETION TIME	AN UPPFR BCUND. T+( 4:THETA.LAMBDA). CN THF 4-TH MAMENT OF THF NETWORK COMPLETION TIME	AN UPPER BOUND, T+( SITHFTA, LAMBDA), ON THE S-TH WIMENT OF THE NETWORK COMPLETION TIME	AN UPPER BOUND, T+( 6;THFTA, LAMBDA), ON THE 6-TH MOMENT OF THE NETWORK COMPLETION TIME	AN UPPER BOUND. T+( 7;THETA,LAMBDA). CN THE 7-TH MOMENT OF THE NETWORK COMPLETION TIME	AN UPPER BOUND. T+( SITHETA.LAMBDA). ON THE 8-TH MOMENT OF THE NETWORK COMPLETION TIME	AN UPPER ACUND. T+( 9:THETA.LAMBDA). ON THE 9-TH MOMENT OF THE NETWORK COMPLETION TIME	AN UPPER POLVO. T+(10;THFTA,LAMBDA). ON THE 10-TH MOMENT OF THE NETWORK COMPLETION TIME *
1+(	1+	1+1	1+	1+	1+0	1+(	1+6	1+(	1+(
ACUND.	BCUND.	BOUND.	BCUND.	BOUND.	ROUND.	BOUND.	BOUND.	ACUND.	POUND.
UPPER	UPPER	UPPER	UPPF	UPPFQ	UPPE 2	UPPFR	OPPER	UPPER	UPPFR
2	Z	7	4	2	4	~	2	7	Z



AN APPROXIMATE NETWORK COMPLETION TIME DISTRIBUTION:

F(.;THETA.\_AMBDA) = .5 \* ( F+(.;THFTA.LAMBDA) + F-(.;THETA.LAMHGA) )

F (	0.406570	.20	0.10CCCD 91:	C-100000 C1) =	C.53C003-01	
F	9.41213D	: 23	0.10c3cD 91;	0.100000 C:1 =	0.500000-01	
ŭ	0.417700	C2:	0-100000 01:	C. 100000 01) =	0.5000000	
F.	0.423260	. 20	C.100000	0.1000CD C11 =	0.5000000	
F	9.42483D	: 20	C.1000000 01:	- 10 CCOD 01) =	C.5906C9-01	
) L	9-434390	: 20	0.1000000	6.1050cn (1) #	0.50000-01	
F	0.439960	. 20	6.1990en c1;	± (1) 0000 U1) =	C.5300C7 00	
ĭ	0.445520	: 20	0.100000	C-100000 01) =	C. 530CCB 60	
ŭ	0.451095	02:	C-1000CD 01:	0.1000000 01) =	0.500000	
ù	5.45665D	: 20	C.10CCED G1:	6- 1000000 FILE	0.500000 00	
F	7.46221D	<b>C2:</b>	0.100Cen C1:	0.100000 01) =	0.500000	
, H	0.467780	:23	0.100000 01:	C. 100000 013 =	0.530000 00	
ĭ	0-47334D	55	0.100000	C. 15 COAN C1) ≠	0.503000	
ĭ	C. 47891D		C.10CCCD 21:	0.100100 C1) =	0.550000 00	
Ĕ	C-48447D	62 ;	C-100000 C1:	C. 100000 C1) =	0.650000 00	
Ä	0.490040	C2:	0.100000 01:	6.1000nD 011 =	0.875C0D 00	
<u>,</u>	0.495ACD	: 23	0.100000 01:	C-100000 01) =	0.375000 00	
Ä	0.501170	(2:	C. 10000CD C1:	C. 100000 C1) =	0.930ccb 0c	
ĭ	0.506730	. 23	0.10CCCD C1:	5.100000 C1) =	00 00000000	
Ĕ	C. 5123rD	. 20	C. 1000CCD C1:	= (10 000Cal -)	6-120000 21	



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C
C
          NEW SUBNETWORK ANALYSIS PROGRAM
C
       IMPLICIT REAL *8 (A-H.O-Z)
C
          FOR THE SAKE OF IDENTIFYING THE APPROPRIATE DIMENSIONS, LET
                M = THE NUMBER OF ACTIVITIES IN THE NETWORK
C
               NMM = NUMBER OF NODES IN THE NETWORK
C
C
               NMMP1 = NMM + 1
C
               N = M + NMM
C
               L = THE LENGTH OF THE CRITICAL PATH
C
               C = THE MAXIMUM NUMBER OF BRANCHES IN A CLUSTER
C
               IEDF = THE NUMBER OF DIVISIONS IN THE EMPIRICAL
C
                       DISTRIBUTION FUNCTION
C
C
C
       INTEGER TAIL( M), HEAD( M). ASSGRP( L.L ). CLINCL(L.L). EGRP(L)
C
      DIMENSION NINCL( C), INCLUS( L. C), NCLINC( L)
C
      DIMENSION FO(IEDF), NLEFD(t. IEDF), NSAVE(IEDF), NIR(L)
C
                         AVG( L), THAT(L)
      DIMENSION
C
      DIMENSION LEFT (M ), LEFT (M ), NONCP (M)
C
      DIMENSION INBASE (NMM) . XNODE (NMM)
C
      DIMENSION X81 (NMMP1). Y1 (NMMP1). REDCOS(N). ISTAT(N)
C
      DIMENSION ICRITP(L) . NINAG(M) . ICRITN(L+1) . CTIME(N) . COT(N)
C
      DIMENSION K3(L). IBH(L), FLO(M), FHI(M), SIGMA(M), BIINV(NMMP1.NMMP1)
C
      REAL
                    MOMENT (L.10)
C
      DIMENSION PP(M),PQ(M)
C
C
          OF COURSE THESE DINENSIONS ARE MERELY UPPER BOUNDS
(
C
      COMMON BIINV.REDCOS.CTIME.XB1.INBASE.HEAD.TAIL.NMMP1.NMM.N.ISTAT
      COMMON N.MPI
      INTEGER TAIL (60), HEAD (60), ASSGRP (25, 25), CLINCL (25, 25), FGRP (25)
      INTEGER SAMSIZ.PANSAM
      DIMENSION NINCL(25), INCLUS(25,25), ACLINC(25)
      DIMENSICA FD(100),NIB(25)
      REAL*8 NLEFD(25,100), NSAVE(100)
      DIMENSION AVG(25) THAT(25)
      DIMENSION INBASE (40)
      DIMENSION XNODE (40)
      DIMENSION XB1(41),Y1(41),REDCOS(100),ISTAT(100)
      DIMENSION BILNY(41,41), KB(25) . IBB(25) . FLO(60) . FHI(60) . SIGMA(60)
      DIMENSION ICRITP(25) NINAG(50) ICRITN(26) COT(100) CTIME(100)
      DIMENSION LEFT(60), LEFTO(60), NONCP(60)
      REAL*8 LAMBDA. MOMENT (25.10)
      DIMENSION PP(60).PQ(60)
      INTEGER OPTON1. OPTON2
          M = THE NUMBER OF ACTIVITIES IN THE NETWORK
C
          NMM = THE NUMBER OF NODES IN THE PERT NETWORK
      READ(5,100)
                    M. NMM
100
      FORMAT (213)
      N=NMM+M
      MP1 = M+1
      NMMP1=NMM+1
         THE ACTIVITIES ARE DESCRIBED IN TERMS OF THEIR NODES
C
         II=THE TAIL NODE, THE ORIGIN NODE
C
         JJ=THE HEAD NODE. THE TERMINAL NODE
C
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FLO = THE LOWER PUINT

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         FHI = THE UPPER POINT
 C
         SIGMA = (FHI - FLO) +DSQRT ( PP+(1-PP)) = STD. DEVIATION
         PP = THE PROBABILITY OF THE LOWER POINT
C
 C
      DO 610 I=1.M
      READ(5,2501) II, JJ, FLO(1 ), FHI(1 ), PP(1)
      PQ(I)=1.00-PP(I)
      SIGMA(I)=(FHI(I)-FLO(I))*DSQRT(PP(I)*PQ(I))
2501
      FORMAT (10X.15.5X.15. 5X.F10.0.F10.0.F10.5)
      COT(I) = PP(I) * FLO(I) * PQ(I) * FHI(I)
      CTIME(I) = COT(I)
      TAIL(I) = II
  610 HEAD(I)=J.
         COT = THE ORIGINAL PIGHT-HAND SIDES. I.E. THE MEANS
C
C
               OF FLO AND FHI
C
         CTIME = THE CURRENT RIGHT-HAND SIDES
      DO 55610 I=MP1.N
55610 CTIMF(1) = ^.
C
              OPTON1 =1 IMPLIES THAT THE PROGRAM WILL TERMINATE AFTER
Ċ
C
                        THE CLUSTERS HAVE BEEN FORMED. NO BOUNDS ON
C
                        THE PROJECT COMPLETION TIME MCMENTS OR
c
                        DISTRIBUTION WILL BE DETERMINED.
C
                            IMPLIES THAT THE NORMAL PROCEDURE WILL BE
              CPTON1
                     NDT = 1
C
                        FOLLOWED.
C
                        IMPLIES THAT THE LOWER BOUNDS ON THE MOMENTS
              OPTON2 =1
c
                         AND THE UPPER BOUND ON THE DISTRIBUTION WILL
                         BE DETERMINED USING ALL ACTIVITY TIMES OUTSIDE
C
                        THE CLUSTER AT THEIR MEAN. THIS PROCEDURE IS
C
                        ONLY GUARANTEED TO BE VALID WHEN ALL
C
C
                         (P,Q) = (.5,.5).
                            IMPLIES THAT THE NORMAL PROCEDURE WILL BE
C
              OPTON2
C
C
      READ(5.77551) OPTON1.0PTON2
77551 FORMAT(1011)
      SMCT90+1NOT9021
      IF(I.GE.1) WRITE(6.77553)
77553 FORMAT(1H1)
      IF(OPTON1 .E0.1) WRITE(6.77552)
77552 FORMAT(1H0+10X+*OPTION1=1 AND THE PROGRAM WILL TERMINATE AFTER THE
     * CLUSTERS HAVE BEEN FORMED. . . . . . . . . . . BOUNDS ON THE PROJECT COMPL
     *ETION TIME MCMENTS OR DISTRIBUTION WILL BE DETERMINED.*)
      IF(OPTCN2 .EQ.1) WRITE(6,77554)
77554 FORMAT (1H0.10x. OPTION2=1 AND THE LOWER BOUNDS ON THE PROJECT COMP
     *ETION TIME MOMENTS AND THE UPPER BOUND ON THE PROJECT COMPLETION T
     *LY GUARANTEED TO PE VALID WHEN ALL (P.Q) = (.5..5) ..)
              IEDF = THE NUMBER OF DIVISIONS IN THE EMPERICAL
C
                     DISTRIBUTION FUNCTION
C
      READ(5.100) IEDF
      WRITE(6.2700)
      FORMAT(1H1+15X+'INITIAL INPUT')
2700
      WRITE(6,2701)
      FORMAT (1HO.10X. ACTIVITY ORIGIN
                                         TERMINAL LOWER POINT
                                                               UPPER P
2701
     *OINT
               MEAN
                      STANDARD DEVIATION
                                           PROB. LOWER DT. 1)
      DD 2704 I=1.M
      WRITF(6.2702) 1.TAIL(1).HEAD(1).FLU(1).FHI(1).CTIME(1).SIGMA(14.PP
2704
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2702 FOFMAT (1H +13X+f3-5X-13-7X-13-5X-F10-4-3X-F10-4-3X-F10-4-4X-F10-4-\*14X.F6.4) C Ç C THE FOLLOWING INDICATORS APE USED: C C C TPARM = 1 IMPLIES THE CRITICAL PATH TIME WHEN ALL ACTIVITY COMPLETION TIMES ARE SET EQUAL TO THEIR MEANS IS REING DETERMINED IMPLIES THAT THE LOWER BOUND ON THE COMPLETION TIME C C FOR THE SUBNETWORK IS BEING DETERMINED IMPLIES THAT THE UPPER BOUND ON THE COMPLETION TIME C FOR THE SUBNETWORK IS BEING DETERMINED WHEN INDEXL=0 IMPLIES THAT THE ASSOCIATES ARE C IPARM > 3 ¢ HEING DETERMINED Ç  $\boldsymbol{c}$ IMPLIES THAT INITIAL CLUSTERS ARE STILL BEING FORMED C INDEXL=1 IMPLIES THAT THE LEFTOVERS, THEIP ELIMINANTS, AND ^ INDEXL=1 C PROLED CLUSTERS ARE BEING DETERMINED IMPLIES THAT THE 2\*\*NINCL( ) RUNS FOR EACH CLUSTER INDEXL=? C C APF BEING MADE C C ICOCP = 0 IMPLIES THAT THE PROCEDURE FOR DETERMINING UPPER ς. BOUNDS ON THE MOMENTS OF THE NETWORK COMPLETION TIME C 7 AND LOWER BOUNDS ON THE DISTRIBUTION OF COMPLETION C TIMES HAS NOT BEEN BEGUN ICBCP = 1 IMPLIES THAT THE PROCEDURE FOR DETERMINING UPPER Ç HOUNDS ON THE MOMENTS OF THE NETWORK COMPLETION TIME C C AND LOWER BOUNDS ON THE DISTRIBUTION OF COMPLETION C TIMES IS BEING INITIALIZED CONTINUE ICBCP = ? IMPLIES THAT THE PROCEDURE FOR DETERMINING UPPER C BOUNDS ON THE MOMENTS OF THE NETWORK COMPLETION TIME C C AND LOWER BOUNDS ON THE DISTRIBUTION OF COMPLETION TIMES IS BEING CAPRIED OUT С C COPY AVAILABLE TO DUC DOES NOT TPARM= 1 PERMIT FULLY LEGIBLE PRODUCTION INDEXL=0 ICBCP=0 601C CONTINUE DO 104 T=1.NMM 104 INPASE(I)=M+I DO 2001 J=1.M ISTAT(J)=C. 1005 DO 2002 J=MP1.N 2002 ISTAT(J)=1 DO 10 II=1.NMMP1 DO 12 L=1.NMMP1 12 B1 INV(L . II) = 0. 10 B11NV(II.II) = 1. DO 30 1=1.8MM  $30 \times B1(I) = 0.$ 

XB1(NMMP1) = 1.

TOLR1=1.00-10

```
48
C
          START THE SIMPLEX ALGORITHM
          SOLVE THE DUAL PROBLEM
C
                                                                                      181
           THE NUMBER OF VARIABLES IS M REAL + NMM SLACKS
                                                                                      182
           FOR A TOTAL OF N VARIABLES
C
350
      CONTINUE
 2800 DO 23 J=1.N
                                                                                      186
       RATS = 0.
                                                                                      187
       IF (ISTAT(J).EQ.1) GO TO 52800
                                                                                      188
                                                                                      189
       IF (J.GT.M) GO TO 22
       RATS = -B_1INV(1, HEAD(J)+1)+BIINV(1, TAIL(J)+1) + CTIME(J)
                                                                                      190
                                                                                      191
      GO TO 52800
   22 RATS =-B1INV(1, J-M+1)
                                                                                      192
52800 REDCOS(J)= RATS
                                                                                      193
                                                                                      194
   23 CONTINUE
                                                                                      195
22800 CONTINUE
                                                                                      196
       TRMAX=1
                                                                                      197
      RMAX=RFDCOS(1)
                                                                                      198
      DO 24 J=2.N
                                                                                      199
      IF(REDCOS(J) .LE. RMAX) GO TO 24
                                                                                      200
      RMAX=PEDCGS(J)
      IRMAX=J
                                                                                      201
24
      CONTINUE
                                                                                      202
                                                                                      203
      IF(RMAX .LE. TOLPI) GO TO 401
                                                                                      204
22824 CONTINUE
      DO 26 L=1.NMMP1
                                                                                      205
                                                                                      206
      IF (IPMAX.GT.M) GO TO 50026
                                                                                      207
      Y1(L) =-B1[NV(L,TAIL([RMAX)+1)+B1[NV(L.HEAD([RMAX)+1)
                                                                                      208
      GO TO 26
50026 \text{ yl(L)} = B1INV(L,IRMAX-M+1)
                                                                                      209
                                                                                      210
   26 CONTINUE
                                                                                      211
      Y1(1) = Y1(1) - CTIME(IRMAX)
      NUMBER = 2
                                                                                      212
                                                                                      213
      DO 27 L=2.NMMP1
      IF(Yi(L) .LE. TOLR1)
                                                                                      214
27
                                NUMBER = NUMBER + 1
      IF(NUMBER .EQ. NMM) GO TO 403
                                                                                      215
                                                                                      216
      RMIN= . 39D ?^
                                                                                      217
      IRMIN=0 .
      DO 32 II=2.NMMP1
                                                                                      218
                                                                                      219
      IF(Y1(II).LE. TOLRI) GO TO 32
                                                                                      220
      RATS = XB1(II)/Y1(II)
                                                                                      221
      RR=RATS-RMIN
                                                                                      222
      IF (RR .GE. 0.D0) GD TO 32
                                                                                      223
      RMIN=PATS
                                                                                      224
      IRMIN= II
                                                                                      225
32
      CONTINUE
                                                                                      226
      DD 33 J=2. NMMP1
                                                                                      227
      WW=81INV(IRMIN ,J)/Y1(IRMIN )
                                                                                      228
      DO 37 L=1.6MMP1
                                                                                      229
37
      B1INV(L \cdot J) = 31INV(L \cdot J) - WW + Y1(L)
                                                                                      230
33
      B1 INV( IRMIN , J)=WW
                                                                                      231
C
                                                                                      232
C
          UPDATE THE BASIC VARIABLES: INBASE AND XBI
                                                                                      233
C
      ISTAT (INBASE(IPMIN-1))=0
                                                                                      234
                                                                                      235
      ISTAT( | RMAX) = 1
                                                                                      236
      INBASE ( TRM IN-1 )= IRMAX
                                                                                      237
      W=X81(IRMIN )/Y1(IRMIN )
                                                                                      238
      DO 38 [=1.NMMP]
                                                                                      239
```

XB1(I)=XB1(I)-Y1(I)+W

299

```
49
       XB1(IRMIN )=W
                                                                                   240
       GO TO 350
                                                                                   241
403
       WRITE(6,530)
                                                                                   242
      FORMAT(1H0.5X. IND FEASIBLE SOLUTION EXISTS. CHECK YOUR INPUT DATA
530
                                                                                   243
      *. * )
                                                                                   244
       WRITE(6.850)
                                                                                   245
850
      FORMAT (1H1)
                                                                                   246
      GD TO 999
                                                                                   247
C
                                                                                   248
C
         END OF THE SIMPLEX ALGORITHM
                                                                                   249
C
                                                                                   250
401
      CONTINUE
                                                                                   251
      IF(ICBCP.EQ.1) GO TO 6008
                                                                                   252
      IF(INDEXL.EQ.2) GO TO 3204
                                                                                   253
C
                                                                                   254
C
         KKK= THE NUMBER OF NODES ON THE CRITICAL PATH
                                                                                   255
C
         KB(L)= THE L-TH NODE IN THE CRITICAL PATH. COUNTING BACKWARDS
                                                                                   256
                     FROM THE TERMINAL NODE
C
                                                                                   257
         KKB= THE NUMBER OF ACTIVITIES ON THE CRITICAL PATH
C
                                                                                   258
C
         IBB(L) = THE L-TH ACTIVITY ON THE CRITICAL PATH, COUNTING
                                                                                   259
C
                      BACKWAPDS FROM THE TERMINAL NODE
                                                                                   260
C
                                                                                   261
      CONTINUE
                                                                                   262
C
                                                                                   263
         INBASE IS A SET OF M INTEGER VARIABLES WHICH INDICATE THE
C
                                                                                   264
         COMPOSITION OF THE CURRENT BASIS. FOR EXAMPLE,
C
                                                                                   265
C
                               IMPLIES THAT THE K-TH COLUMN IN THE BASIS B
                                                                                   266
               INBASE(K) = 7
                               CORRESPONDS TO THE 7-TH VARIABLE
                                                                                   267
C
C
                                                                                   268
C
                                                                                   269
         ISTAT INDICATES THE BASIC STATUS OF FACH VARIABLE
C
                                                                                   270
                              IMPLIES THAT THE K-TH VARIABLE IS IN THE
                                                                                   271
C
               ISTAT(K) = 1
C
                              DUAL BASIS
                                                                                   272
C
               ISTAT(K) = 0
                              IMPLIES THAT THE K-TH VARIABLE IS NOT IN THE
                                                                                   273
C
                                                                                   274
                              DUAL BASIS
                                                                                   275
C
C
                                                                                   276
C
         THE FOLLOWING STATEMENTS DETERMINE THE NODES AND ACTIVITIES ON
                                                                                   277
                                                                                   278
C
         THE CRITICAL PATH
                                                                                   279
C
                                                                                   280
C
         THE DUAL SOLUTION IMPLIES THE FOLLOWING OPTIMAL SOLUTION TO THE
C
                                                                                   281
         PRIMAL PERT PROBLEM. HOWEVER SOME OF THE NODE TIMES(OTHER THAN
                                                                                  282
C
         THE LAST ONE) MAY BE HIGHER THAN NECESSARY. THUS IN
                                                                                   283
C
         DETERMINING THE CRITICAL PATH AN ALTERNATIVE OPTIMAL SOLUTION
                                                                                  284
C
         MAY HAVE TO BE IDENTIFIED.
                                                                                  285
                                                                                  286
C
         RIINV IS NOT CHANGED.
                                                                                  287
      MMM.1=1 SCOE8 OO
                                                                                  288
                                                                                  289
83002 XNCDE(1)=811NV(1.1+1)
                                                                                  290
      KKK=1
                                                                                  291
      KH(1)=NMM
                                                                                  292
A3301 IK=KB(KKK)
                                                                                  293
C
         DETERMINE WHETHER THE TIME TO REACH NODE
                                                      IK
                                                             IS NECESSARILY
                                                                                  294
         AS LARGE AS INDICATED FROM THE DUAL SOLUTION
                                                                                  295
                                                                                  296
      SMIN=999999.
                                                                                  297
```

ISMIN=0

DO 83000 T=1.M San State of State of

```
50
        IF(HEAD(I).NF.IK) GO TO 83000
                                                                                   300
        SHACK=XNODE(HEAD(I))-XNODE(TAIL(I))-CTIME(I)
                                                                                   30 1
        IF(SLACK.GE.SMIN) GO TO 83000
                                                                                   302
                                                                                   303
       SMIN=SLACK
                                                                                   304
       ISMIN=I
                                                                                   305
 83000 CONTINUE
                                                                                   306
       IF(SMIN.LT.0.0001) GO TO 83003
 C
                                                                                   307
 C
           THE TIME FOR NODE IK WAS UNNECCESSABILY LARGE
                                                                                   308
                                                                                   309
 C
       XNODE([K]=XNODE([K]-SMIN
                                                                                   310
                                                                                   311
       KKK=KKK-1
                                                                                   312
       GO TO 93001
 83003 TBP(KKK)=ISMIN
                                                                                   313
                                                                                   314
       KKK=KKK+1
                                                                                   315
       KP(KKK) =TAIL(ISMIN)
                                                                                   316
       IF(TAIL(ISMIN).GT.1) GO TO 83001
                                                                                   317
       KKB=KKK-1
       IF (INDEXL. FQ. 1) GO TO 3121
                                                                                   318
       TPAPM= I PAPM+1
                                                                                   319
       IF ( | PARM - GT - 4 ) GO TO 2910
                                                                                   320
       IF ( IPAR V. EQ. 3 ) GO TO 6400
                                                                                   321
       IF (1PARM.EQ.4) GO TO 6401
                                                                                   322
                                                                                   323
          ICPITP(L)= THE L-TH ACTIVITY ON THE ORIGINAL CRITICAL PATH
                                                                                   324
           KCDB= THE NUMBER OF ACTIVITIES ON THE ORIGINAL CRITICAL PATH
                                                                                   325
 C
                                                                                   326
 C
                                                                                   327
       TOTAL = RIINV(1.NMMP1)
                                                                                   328
       KCPE=KK9
                                                                                   329
       ICFITN(1) = NMM
                                                                                   330
       DO 2802 I=1.KCPR
                                                                                   331
       ICRITN(I+1) = KE(I+1)
                                                                                   332
 2802
       ICRITP(I)=IRB(I)
                                                                                   333
       X=TOTAL
       WRITE(6.851) X
                                                                                   334
 851
       FORMAT(1H0.5x. THE CRITICAL PATH TIME WHEN EACH ACTIVITY S COMPLE
                                                                                   335
      *TION TIME IS SET EQUAL TO ITS MEAN IS = *.D15.5)
                                                                                   336
       WPITE(6.7606) KKK
                                                                                   337
  7606 FORMAT(1H0.10x. THF 1.13. NODES ON THE CRITICAL PATH ARE AS FOLLO
                                                                                   338
      *wS BEGINNING WITH THE TERMINAL NODE: 1)
                                                                                   339
                                                                                   340
       WRITE(6,7707) (KB(I), I=1,KKK)
                                                                                   341
  7707 FORMAT(15X,20(13,1,1))
                                                                                   342
       WRITE(6.771)) KKB
      FORMAT(1Hg.10x. THE 1,13. CRITICAL ACTIVITIES ARE AS FOLLOWS REGI
                                                                                   343
 7710
      *NNING WITH THE TERMINAL ACTIVITY: 1)
                                                                                   344
       WPITF(6,7707) (IBB(I),I=1,KKB)
                                                                                   345
       READ(5.2920) THETA+LAMBDA
                                                                                   346
                                                                                   347
 2920
        FORMAT(2FE.2)
       WRITE(6.3071) THETA.LAMUDA
                                                                                   348
                                               LAMBDA = '.E15.5)
                                                                                   349
 3071
       FORMAT (1HO .1 ) X . THETA = . . E15.5. .
                                                                                   350
          SAMSIZ = THE NUMBER OF ACTIVITY TIME CONFIGURATIONS (O BE
                                                                                   351
 C
                    RANDOMLY SELECTED FOR CONSIDERATION IN EACH CLUSTER
                                                                                   352
 C
                                                                                   353
 C
              SINCE THIS IS A RANDOM SAMPLE . SOME PERCENTILE
                                                                                   354
       NOTE:
                                                                                   355
              COMBINATIONS MAY BE CONSIDERED MORE THAN ONCE.
 C
                                                                                   356
- C
       READ (5.3209) SAMSIZ
                                                                                   357
```

3209 FORMAT (110)

C

358

```
51
C
         THE COMPLETION TIME FOR ALL ACTIVITIES IS SET TO THEIR LOWER
                                                                                   360
c
          PERCENTILE. THE RESULTING CRITICAL PATH TIME IS A LOWER
                                                                                   361
C
          BOUND ON THE EXPECTED CRITICAL PATH TIME.
                                                                                   362
C
                                                                                   363
      DO 6402 I=1.M
                                                                                   364
 6402 \text{ CTIME}(I) = \text{FLO}(I)
                                                                                   365
      CALL BINVA(62800)
                                                                                   366
                                                                                   367
6420
      CPLB= Blinv(1.NMMP1)
      WPITE(6.6405) CPLB
                                                                                   368
6405 FORMAT(1H2,5X, 'A LOWER BOUND ON THE EXPECTED CRITICAL PATH TIME IS
                                                                                   369
                                                                                   370
     * = ".F15.5)
      WRITE(6,7606) KKK
                                                                                   371
                                                                                   372
      WPITE(6.7707) (KB(I).I=1.KKK)
                                                                                   373
      WRITF(6,7710) KKB
                                                                                   374
      WPITE(6.7707) (IBB(I).I=1.KKB)
                                                                                   375
C.
         THE COMPLETION TIME FOR ALL ACTIVITIES IS SET TO THEIR UPPER
                                                                                   376
C
         PERCENTILE. THE RESULTING CRITICAL PATH TIME IS A UPPER
                                                                                   377
C
         BOUND ON THE EXPECTED CRITICAL PATH TIME.
                                                                                   378
C
                                                                                  379
C
                                                                                  380
      DO 6406 I=1.M
                                                                                  381
 6406 CTIMF(I) = FHI(I)
                                                                                  382
      CALL BINVA($2800)
 6401 CPUB= B1INV(1,NMMP1)
                                                                                  383
                                                                                  384
      WRITF(6,6409) CPUB
      FORMAT(1HC.5X. "A UPPER BOUND ON THE EXPECTED CRITICAL PATH TIME IS
6409
                                                                                  385
                                                                                  386
     * = *.E15.51
                                                                                  387
      WRITE(6,7606) KKK
      WRITE(6,7707) (KB(1),1=1,KKK)
                                                                                  388
                                                                                  389
      WPITF(6,7710) KKR
      WRITF(6,7707) (IBB(I), !=1,KKB)
                                                                                  390
                                                                                  391
C
C
         FD(I) = THE LOWER BOUND ON THE EXPECTED CRITICAL PATH TIME
                                                                                  392
                                                                                  393
C
                  PLUS 1/1FDF OF THE DISTANCE TO THE UPPER BOUND
C
         NLEFD(IR,I) = THE SUM OF (THE CRITICAL PATH TIME FOR A
                                                                                  394
                        CONFIGURATION * THE PROBABILITY OF THE
C
                                                                                  395
C
                        CONFIGURATION --- WHEN THE CRITICAL PATH TIME IS
                                                                                  396
C
                        <= FD(I) ) * (THE NUMBER OF POSSIBLE
                                                                                  397
                                                                                  398
                        CONFIGURATIONS) / (THE SAMPLE SIZE)
C
                                                                                  399
C
                        FOR THE IR-TH CLUSTER
C
                                                                                  400
                                                                                  401
C
         FD AND NLEFD ARE USED TO BUILD AN "EMPIRICAL" DISTRIBUTION OF
                                                                                  402
C
         THE CRITICAL PATH TIMES
                                                                                  403
C
                                                                                  404
      C=(CPUB-CPLB)/IEDF
      DO 6412 K=1.KCPB
                                                                                  405
                                                                                  406
      DO 6412 I=1. IEDF
      FD(I)=CPLR+I*C
                                                                                  407
                                                                                  408
      NLEFD( K.I)=0.DO
6412
                                                                                  409
C
                                                                                  410
C.
         THE ASSOCIATE GROUPS ARE NOW FORMED
                                                                                  411
C
                                                                                  412
      WPITE(6,3165)
                                                                                  413
3165
      FORMAT(1H1,5X, THE ASSOCIATES ARE NOW IDENTIFIED:")
                                                                                  414
      11111=1
                                                                                  415
      DO 2825 I=1.M
2825
                                                                                  416
      CTIME(I)=COT(I)
                                                                                  417
      IWWWG=[CRITP(1)
                                                                                  418
      CHANG= LAMBDA*SIGMA(IWWWQ)
```

TFX=CDT( IWWWQ ) - CHANG

```
52
       IF (TEX.LT.C.C) CHANG=COT (IWWWQ)
                                                                                   420
       CTIME(IWWWQ)=COT(IWWWQ)-CHANG
                                                                                   421
       CALL BINVA(62900)
                                                                                  422
2801
                                                                                   423
       CONTINUE
                                                                                  424
       IF(ISTAT(IwwwQ).EO.1) CALL BINV1(622825.COT(IWWWQ).CTIME(IWWWQ).
      *IWWWO1
                                                                                  425
       PFDCOS(IWWWQ) = PEDCOS(IWWWQ)+CDT(IWWWQ)-CTIME(IWWWQ)
                                                                                  426
22825 CTIMF(IWWWQ)=COT(IWWWQ)
                                                                                  427
       IWWWQ=ICRITP(IIIII)
                                                                                  428
       CHANG= LAMBDA+SIGMA(IWWWO)
                                                                                  429
       TEX=COT(IWWWQ)-CHANG
                                                                                  4 30
       IF(TEX.LT.0.0) CHANG=COT(IWWWQ)
                                                                                  431
       CTIME(IWWWO)=COT(IWWWQ)-CHANG
                                                                                  432
       IF (ISTAT(IWWWQ).EQ.1) CALL BINV1(622900,CTIME(IWWWQ).COT(IWWWQ).
                                                                                  433
                                                                                  434
      *IWWWO)
       REDCOS(IWWWQ)=REDCOS(IWWWQ)-COT(IWWWQ)+CTIME(IWWWQ)
                                                                                  435
       GD TD 32800
                                                                                  436
                                                                                  437
C
C.
          DETERMINE ASSOCIATE GROUP
                                                                                  438
C
                                                                                  439
2910
      NINAG(IIIII)=0
                                                                                  440
      DO 2911 K=1.KKB
                                                                                  441
                                                                                  442
      KK=1
2913
      IF(IBB(K).EQ.ICRITP(KK)) GO TO 2911
                                                                                  443
                                                                                  444
       IF(KK.GE.KCP3) GO TO 2912
                                                                                  445
       KK=KK+1
      GO TO 2913
                                                                                  446
                                                                                  447
      NINAG(IIIII)=NINAG(IIIII)+1
2912
       ASSGRP(IIIII, NINAG(IIIII))=IBH(K)
                                                                                  448
                                                                                  449
2911
      CONTINUE
      WRITE(6,2915) ITIII, ICRITP(IIIII), NINAG(7*III)
                                                                                  450
      FORMAT(1Hc+10X, THE NUMBER OF ASSOCIATES ASSOCIATED WITH THE *+13+
                                                                                  451
2915
     **-TH CRITICAL PATH ACTIVITY. I.E. ACTIVITY *. 13. *. IS = *. I3)
                                                                                  452
                                                                                  453
       IDUCK=NINAG(IIIII)
       IF(IDUCK.EQ.0) GO TO 2810
                                                                                  454
       WRITE(6,2916) (ASSGRP([]][],[],[],[=],[DUCK)
                                                                                  455
2916 FORMAT (1H0,15X, THE ACTIVITIES IN THE ASSOCIATE GROUP ARE AS FOLLO
                                                                                  456
                                                                                  457
     *WS*,/,15X,50([3,*,*])
                                                                                  458
2810
      [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
                                                                                  459
       IF(IIIII.LF.KCPB) GO TO 2801
                                                                                  460
C
                                                                                  461
C
          DETERMINE THE CLUSTERS
                                                                                  462
                                                                                  463
C
               THE CLUSTERS ARE POOLED TOWARD THE TERMINAL NODE
               NCLUS = THE NUMBER OF NON-EMPTY CLUSTERS
                                                                                  464
C
               NINCL(I) = THE NUMBER OF ACTIVITIES IN THE I-TH CLUSTER
                                                                                  465
C
               INCLUS(I, J) = THE J-TH ACTIVITY IN THE I-T4 CLUSTER
                                                                                  466
C
                                                                                  467
               NCLINC(I) = THE NUMBER OF CLUSTERS COMPRISING THE I-TH
C
                    CLUSTER AFTER POOLING
                                                                                  468
C
               CLINCL(I+J) = THE J-TH CLUSTER WHICH HAS BEEN POOLED INTO
                                                                                  469
C
                                                                                  470
C
                    THE I-TH CLUSTER
                                                                                  471
C
               NCLING AND CLINCL HELP KEEP TRACK OF WHICH CLUSTER THE
                                                                                  472
                                                                                  473
C
               CRITICAL PATH ACTIVITIES ARE IN
                                                                                  474
C
                                                                                  475
•
         BELOW FORMS CLUSTERS BY PUTTING EACH CRITICAL PATH ACTIVITY IN
                                                                                  476
                                                                                  477
         SEPARATE CLUSTER AND THEN ADDING EACH CRITICAL PATH ACTIVITY'S
C
                                                                                  478
         ASSOCIATES TO ITS CLUSTER
C
```

```
53
                                                                                    480
       NCLUS=KCPB
                                                                                    481
       DD 3020 T=1.KCPB
       NCL INC(I)=1
                                                                                    482
                                                                                    483
       CLINCL (I.1)=I
                                                                                    484
       NINCL(I) = NINAG(I)+1
       INCLUS([,1)=[CRITP(])
                                                                                    485
                                                                                    486
       IF(NINAG(1).FQ.Q) GO TO 3020
                                                                                    487
       IDUCK=NINCL(I)
                                                                                    488
       DO 3021 J=2. IDUCK
                                                                                    489
       JJ=J-1
                                                                                    490
3021
       INCLUS(I.J) = ASSGRP(I.JJ)
3020
                                                                                   491
      CONTINUE
                                                                                    492
                                                                                    493
C
          BELOW POOLS CLUSTERS FORMED FROM ASSOCIATES
                                                                                   494
C
                                                                                   495
       TA=C
                                                                                   496
3031
       IA=IA+1
                                                                                   497
       IF(IA.GE.KCPB) GO TO 30 30
                                                                                   498
       IF (NCLUS.EQ.1) GO TO 3030
                                                                                   499
       IDIA=NINCL (IA)
                                                                                   500
       IF(IDIA.EQ.0) GO TO 3031
       IAA=IA+1
                                                                                   501
                                                                                   502
      DO 3023 II=IAA,KCPB
      IDII=NINCL(II)
                                                                                   503
                                                                                   504
       IF(IDII.FQ.0) GO TO 3023
      DO 3025 I=1.IDIA
                                                                                   505
                                                                                   506
      DO 3025 J=1. IDII
                                                                                   507
      IF (INCLUS(II.J).EQ.INCLUS(IA.I)) GO TO 3027
                                                                                   508
      CONTINUE
3025
                                                                                   509
      GO TO 3323
                                                                                   510
      NCLUS=NCLUS-1
3027
                                                                                   511
      DO 3028 J=1.IDII
                                                                                   512
      Dn 3029 I=1.IDIA
      IF(INCLUS(II.J).EQ.INCLUS(IA.I)) GO TO 3028
                                                                                   513
                                                                                   514
      CONTINUE
      NINCL(IA)=NINCL(IA)+1
                                                                                   515
                                                                                   516
       INCLUS(IA.NINCL(IA) )=INCLUS(II.J)
                                                                                   517
3028
      CONTINUE
                                                                                   518
      NINCL(II)=?
                                                                                   519
      NCLINC(IA)=NCLINC(IA)+1
                                                                                   520
      CLINCL(TA, NCLINC(IA)) = II
                                                                                   521
      NCLINC(II)=7
                                                                                   522
      CONTINUE
3023
                                                                                   523
      GO TO 3031
                                                                                   524
      CONTINUE
3030
                                                                                   525
C
          BELOW DESCRIBES CLUSTERS AFTER POOLING BASED ON THE ASSOCIATES
C
                                                                                   526
                                                                                   527
C
                                                                                   528
       WRITE(6,3033) NCLUS
      FORMAT (1H1.10X. THERE ARE 1.13. NONEMPTY CLUSTERS AFTER POOLING D
                                                                                   529
3033
     *N THE BASIS OF ASSOCIATES ONLY.")
                                                                                   530
                                                                                   531
      II=C
                                                                                   532
      DO 3034 T=1.KCPB
       IF(NINCL(I).FO.0) GO TO 3034
                                                                                   533
                                                                                   534
       TI=11+1
                                                                                   535
      IDUCJ=NINCL(I)
                                                                                   536
      WRITE(6.3035) 1.(INCLUS(1.J).J=1.IDUCJ)
      FORMAT(1H2+10X+ THE ACTIVITIES IN THE ++13+++H CLUSTER ARE AS FOL
                                                                                   537
3035
                                                                                   538
     *LOWS: 1,/,15X,50([3,*,*))
```

CONTINUE

3034

```
C
                                                                                  540
C
          DESCRIBES WHERE EACH ACTIVITY IS BEFORE ELIMINANTS ARE
                                                                                  541
C
          CONSIDERED
                                                                                  542
C
                                                                                  543
C
                                                                                  544
C
          FXAMINE EACH ACTIVITY AND DETERMINE WHICH CLUSTER. IF ANY. IT IS
                                                                                  545
C
                                                                                  546
C
                             IMPLIES THAT THE I-TH ACTIVITY IS NOT IN ANY
                                                                                  547
               LEFT(I) = 0
                                                                                  548
                             CLUSTER
               LEFT(I) = J
C
                             IMPLIES THE I-TH ACTIVITY IS IN THE J-TH
                                                                                  549
C
                             CLUSTER
                                                                                  550
                                                                                  551
C
       WRITE(6.3104)
                                                                                  552
      FORMAT(1HC+10X++THE CLUSTER TO WHICH EACH ACTIVITY BELONGS: 1./.15X
                                                                                  553
3104
      *. " (ZERO IMPLIES THAT THE ACTIVITY IS NOT IN ANY CLUSTER) )
                                                                                  554
                                                                                  555
       DO 3101 I=1.M
      LEFT(I)=C
                                                                                  556
       DO 3102 J=1.KCPB
                                                                                  557
                                                                                  558
       IF (NINCL(J).FO.0) GO TO 3102
       IDUCK=NINCL(J)
                                                                                  559
                                                                                  560
      DO 3110 K=1. IDUCK
                                                                                  561
       IF(I.FO.INCLUS(J.K)) GO TO 3107
                                                                                  562
      CONTINUE
3110
3102
      CONTINUE
                                                                                  563
                                                                                  564
      GO TO 3101
                                                                                  565
3107
      LFFT(T)=J
3101
                                                                                  566
       WRITE(6,3103) I,LEFT(I)
3103
      FORMAT(1H +15x, THE ++13. -TH ACTIVITY IS IN THE 1.13. -TH CLUSTER
                                                                                  567
      **)
                                                                                  568
                                                                                  569
       INDEXL=1
                                                                                  570
C
C
          LEFTOVERS ARE ACTIVITIES NOT IN CLUSTERS AFTER ASSOCIATES HAVE
                                                                                  571
          HEEN CONSIDERED BUT SEFORE ELIMINANTS HAVE BEEN CONSIDERED
                                                                                  572
C
                                                                                  573
C
                                                                                  574
C
C
          DETERMINE THE NUMBER OF LEFTOVERS. NLEFT
                                                                                  575
                            IMPLIES THAT THE L-TH LEFTOVER IS THE J-TH
                                                                                  576
Ç
               LEFTO(L) = J
                                                                                  577
(
                              ACTIVITY
                                                                                  578
C
                                                                                  579
      NLEFT= )
      DO 3122 J=1,M
                                                                                  580
                                                                                  581
      IF(LFFT(J).NF.0) GD TO 3122
      NLEFT=NLEFT+1
                                                                                  582
                                                                                  583
      LEFTO(NLFFT) "J
                                                                                  584
      CONTINUE
3122
                                                                                  585
      WRITE(6.3123) NLFFT
      FORMAT (1H0.10X. THERE ARE 1.13. ACTIVITIES NOT IN ANY CLUSTER YE
                                                                                  586
3123
                                                                                  587
     *T. 1)
      WRITE(6.3323)
                                                                                  588
      FORMAT(1H1.5X. THE ELIMINANTS OF EACH NUN-CRITICAL-PATH ACTIVITY A
                                                                                  589
3323
                                                                                  590
     *RE NOW DETERMINED: 1)
                                                                                  591
C
C
          ELIMINANTS FOR FACH NON-CRITICAL-PATH ACTIVITY ARE NOW
                                                                                  592
                                                                                  593
C
          DETERMINED
                                                                                  594
C
               NNNCP = THE NUMPIER OF ACTIVITIES NOT ON THE CRITICAL PATH
               NONCP(LE) = THE LE-TH ACTIVITY NOT UN THE CRITICAL PATH
                                                                                  595
C
                                                                                  596
                                                                                  597
      NNNCP= M-KCP9
                                                                                  598
      LF=C
                                                                                  599
      DO 5000 I=1.M
```

```
600
5001
                                                                                 601
       IF(I.Eg.ICRITP(J)) GO TO 5000
                                                                                 602
       IF (J.LE.KCPB) GO TO 5001
                                                                                 603
                                                                                 604
5002
      LE=LE+1
                                                                                 605
      NONCP(LE)=I
                                                                                 606
500r
      CONTINUE
                                                                                 607
      WRITE(6.5005) NNNCP
     FORMAT (1HO . 25x . THERE ARE . 13. ACTIVITIES NOT ON THE CRITICAL PA
                                                                                 608
5005
                                                                                 609
            THEY ARE AS FOLLOWS: 1)
      IF(NNCP.FG.0) GO TO 3124
                                                                                 610
                                                                                 611
      DO 5006 I=1.LE
5006
      WRITE(6,5007) I,NONCP(I)
                                                                                 612
                                                                                 613
50C7
      FORMAT(IH .15X.13.*.
                                                                                 614
      IF(NNNCP.FQ.0) GO TO 3124
                                                                                 615
      LF=n
                                                                                 616
3126 LE=LE+1
      IF (ISTAT(IWWWQ).F2.1) CALL BINV1(623127.COT(IWWWQ).CTIME(IWWWQ).
                                                                                 617
                                                                                 618
      PEDCOS (IWWWQ) = RFDCOS(IWWWQ)+CT[ME([WWWQ)+COT(IWWWQ)
                                                                                 619
                                                                                 620
23127 CONTINUE
                                                                                 621
      CTTME(IWWWQ) = COT(IWWWQ)
                                                                                 622
      CTIME(NONCP(LE)) = COT(NONCP(LE)) + THETA*SIGMA(NONCP(LE))
      IF (ISTAT(NONCP(LE)).EQ.1) CALL BINV1(67756.CTIME(NONCP(LE)).
                                                                                 623
                                                                                 624
          COT (NONCP(LE)), NONCP(LE))
      REDCOS(NCNCP(LE))=REDCOS(NONCP(LE))-COT(NONCP(LE))+CTIME(NONCP(LE)
                                                                                 625
                                                                                 626
     * )
                                                                                 627
 7756 IWWWG = NENCP(LE)
      WRITE(6,3152) NONCP(LF), CTIME(NONCP(LE))
                                                                                 628
     FORMAT(1H0.///. 5X. THE COMPLETION TIME FOR THE .13. TH ACTIVITY
                                                                                 629
                                                                                 630
     * HAS BEEN CHANGED TO ".E15.5)
                                                                                 631
      GO TO 22800
                                                                                 632
      CONTINUE
3121
                                                                                 633
C
          DETERMINE THE ELIMINANTS OF THE LE-TH ACTIVITY NOT ON THE
                                                                                 634
C
                                                                                 635
          CRITICAL PATH
C
                         = THE NUMBER OF ELIMINANTS FOR THE LE-TH
                                                                                 636
C
               NE.
                                                                                 637
                           ACTIVITY NOT ON THE CRITICAL PATH
C
                            = THE J-TH ELIMINANT FOR THE LE-TH ACTIVITY
                                                                                 638
C
               EGRP(J)
                              NOT ON THE CRITICAL PATH
                                                                                 639
C
C
                                            COPY AVAILABLE TO DDC DOES NOT
                                                                                 641
      NE=C
                                                                                 642
      DO 3130 K=1.KCPB
                                             PERMIT FULLY LEGIBLE PRODUCTION
                                                                                 643
      DO 3131 I=1.KKB
      IF ( 18B( 1) . E7 . 1CR | TP (K ) ) GO TO 3130
                                                                                 645
3131
      CONTINUE
                                                                                 646
      NE=NE+1
                                                                                 647
      FGPP(NE)=ICRITP(K)
                                                                                 648
      CONTINUE
313C
                                                                                 649
      WRITE(6,3133) NE,NONCP(LE)
     FORMAT(1H0.10X. THERE ARE T.IS. FLIMINANTS CORPESPONDING TO ACTIV
                                                                                 650
3133
                                                                                 651
     *ITY '+13)
                                                                                 652
      IF(NE-EQ-0) GO TO 3171
                                                                                 953
      DO 3135 K=1.NE
                                                                                 654
      WRITE(6,3136) K, NONCP(LE) + EGPP(K)
3135
     FORMAT(1H +14X++THE ++13++-TH ELIMINANT CORRESPONDING TO ACTIVITY
                                                                                 155
3136
                                                                                 656
     **.13.* IS ACTIVITY *.131
                                                                                 657
                                                                                 658
          DETERMINE WHETHER NONCP(LE) IS AN ASSOCIATE
C
                       IF NUNCP(LF) IS AN ASSOCIATE
```

JA = 1

```
660
   C
                                                                                     661
         K=NCNCP(LE)
                                                                                     662
         JA=1
                                                                                     663
         IF(LEFT(K).EQ.O) JA=2
                                                                                     664
         IF(JA.EQ.2) GO TO 5010
                                                                                     665
                                                                                     666
         IT=LFFT(K)
                                                                                     667
   C
             THE IT-TH CLUSTER IS EXPANDED TO INCLUDE ELIMINANTS
                                                                                     668
   C
                                                                                     669
         GO TO 5011
                                                                                     670
         CONTINUE
                                                                                     671
   5010
                                                                                     672
  C
   C
             ITTTT IS THE ACTIVITY NUMBER OF THE FIRST FLIMINANT
                                                                                     673
            IT IS THE CLUSTER TO WHICH THE FIRST ELIMINANT CURRENTLY BELONG
  C
                                                                                     674
                                                                                     675
   C
         ITTT=FGRF(1)
                                                                                     676
         IT=LEFT(ITTT)
                                                                                     677
         LEFT (NONCP(LE))=IT
                                                                                     678
                                                                                     679
  C
            THE IT-TH CLUSTER IS EXPANDED TO INCLUDE FLIMINANTS
                                                                                     680
                                                                                     681
  C
         NINCL(IT)=NINCL(IT)+1
                                                                                     682
         INCLUS(IT, NINCL(IT)) = NCNCP(LF)
                                                                                     683
                                                                                     684
         IF(NE-EQ-1) GO TO 3171
  5011
                                                                                     685
         DO 3172 J=JA, NE
                                                                                     686
  C
            IU IS THE ACTIVITY NUMBER OF THE NEXT ELIMINANT
                                                                                     687
            IF IU IS IN CLUSTER K. THEN CLUSTER K IS POOLED INTO CLUSTER IT
  C
                                                                                     688
                                                                                     689
         TU=EGRP(J)
                                                                                     590
                                                                                     691
         K=LFFT(IU)
         IF(IT.EQ.K) GO TO 3172
                                                                                     692
  3182
                                                                                     693
         NCLUS=NCLUS-1
         IW=NCLINC(K)
                                                                                     694
                                                                                     695
         DO 3183 IA=1, IW
                                                                                     696
         LFFT(ICRITP(CLINCL(K.IA)))=IT
                                                                                     697
         NCL INC (IT) = NCL INC(IT)+1
         CLINCL(IT.NCLINC(IT))=CLINCL(K, IA)
                                                                                     698
  3183
                                                                                     699
         NCL INC (K)=0
                                                                                     700
         IW=NINCL(K)
                                                                                     701
       · NINCL(K)=0
                                                                                     702
         DO 3184 TA=1.TW
                                                                                     703
         LEFT(INCLUS(K.IA))=IT
                                                                                     704
         NINCL(IT)=NINCL(IT)+1
                                                                                     705
  3184
         INCLUS(IT.NINCL(IT))=INCLUS(K.IA)
                                                                                     706
  3172
         CONTINUE
                                                                                     707
  3171
         CONTINUE
                                                                                     708
         IF(LF.LT.NNNCP) GO TO 3126
                                                                                     709
  FND OF POOLING BASED ON ELIMINANTS EXCEPT FOR THE FOLLOWING
                                                                                     710
  C
                                                                                     711
  C
            DESCRIPTION
                                                                                     712
 C
                                                                                     713
         WRITE(6,3173) NCLUS
                                                                                     714
         FORMAT (1H1.05X. THERE ARE .. I3. CLUSTERS.)
  3173
         DO 3176 I=1.KCP9
                                                                                     715
                                                                                     716
         IF(NINCL(I).EQ.0) GO TO 3176
                                                                                     717
         IDD=NINCL(I)
         write(6,3174) NINCL(1)+1+(INCLUS(1+J)+J=1+1DD)
                                                                                     718
3174
         FORMAT (140.10X. THERE ARE ".13." ACTIVITIES IN THE ".13."-TH CLUST
                                                                                     719
```

JA = 2 IF NONCP(LE) IS NOT AN ASSOCIATE

C

```
THEY ARE AS FOLLOWS: 4.20x.50(13.1.1)
                                                                                 72C
                                                                                 721
       TOUCK=NCLINC(I)
       WRITE(6.3175) NCLINC(I).(CLINCL(I.J).J=1.IDUCK)
                                                                                 722
3175 FORMAT (1H0.15%.13.) CLUSTERS HAVE BEEN POOLED TO MAKE THIS CLUSTER
                                                                                 723
     *. THEY WERE AS FOLLOWS: 1./.20X.50([3.1.1))
                                                                                 724
      CONTINUE
                                                                                725
3176
      IF (SAMSIZ-LE-0) WRITE(6-6045)
                                                                                726
       IF (SAMSIZ.GT.C) WRITE(6.6056) SAMSIZ.SAMSIZ
                                                                                727
 6055 FORMAT( 5x. THE FULLOWING TABLES WERE DETERMINED CONSIDERING AT M
                                                                                728
                                                                                729
     *OST '.IB. ACTIVITY CONFIGURATIONS PER CLUSTER. ... 11x. IF THERE A
     *RE NO MORE THAN ".IS." ACTIVITY CONFIGURATIONS IN A CLUSTER."./.II
                                                                                730
     *X. THEN ALL ACTIVITY CONFIGURATIONS ARE EXPLICITLY CONSIDERED. AND
                                                                                731
     * NO SAMPLING IS DONF. 1)
                                                                                732
 6045 FORMAT (5X.* THE FOLLOWING TABLES WERE DETERMINED CONSIDERING ALL
                                                                                733
     * ACTIVITY CONFIGURATIONS. 1)
                                                                                734
                                                                                735
C
          MARNING: THE SYSTEM SUBROUTINE CLOCK MAY NOT BE A PART OF
                                                                                736
C
         ALL SYSTEMS. KRAN NEFDS TO BE A RANDOM SEFD.
                                                                                737
                                                                                738
C
      CALL CLOCK (XRAN)
                                                                                739
                                                                                740
      IYUTS = XRAN
      WRITE (6.3238) IVUTS
                                                                                741
 3238 FORMAT (1H).5X. THE INITIALIZATION PARAMETER FOR ANY SAMPLING IS I
                                                                                742
                                                                                743
     *Y = *.IIC)
                                                                                744
C
         STATEMENT NUMBER 3124 MARKS THE END OF POOLING CLUSTERS BASED
                                                                                745
c
               ON LEFTOVERS AND ELIMINANTS
                                                                                746
C
                                                                                747
3124
      CONTINUE
                                                                                748
                                                                                749
      IF(CPTON1 .EQ.1) GO TO 399
C
                                                                                750
                                                                                751
C
c
         THE FINAL CLUSTERS HAVE NOW BEEN DETERMINED
                                                                                752
         THE 2**NINCL(I) RUNS ARE NOW MADE FOR ALL I WITH NINCL(I)>C.
                                                                                753
c
C
                                                                                754
                                                                                755
C
6008
      IF (ICBCP.EQ.1) ICBCP=2
                                                                                756
                                                                                757
      INDEXL=2
      IF (CPTON2 .EQ.1) GO TO 87701
                                                                                758
      IF(ICACP.EQ.2) GO TO 87701
                                                                                759
                                                                                760
      DO 17701 T=1,M
                                                                                761
17701 COT(I)=FLO(I)
                                                                                762
87701 CONTINUE
      IR=C
                                                                                763
                                                                                764
3200
      IR=IR+1
      IF(IP.GT.KCPB) GO TO 3208
                                                                                765
                                                                                766
      IF(NINCL(IR).EQ.O) GO TO 3200
      00 6031 1=1.10
                                                                                767
      MOMENT(IR.I) = 0.00
                                                                                768
5031
                                                                                769
      DO 9101 1=1.1EDF
                                                                                770
9101
      NLFFD(IR.I)=1.D0
      1P = (
                                                                                771
3310
                                                                                772
      NIB(TP)=C
                                                                                773
            = NUMBER OF ACTIVITY CONFIGURATIONS IN THE SAMPLE
      NIB
                                                                                774
C
      NSAVE = VECTOR CONTAINING THE UPPER BOUNDS ON THE NETWORK
                                                                                775
C
                                                                                776
C
              COMPLETION TIME DISTRIBUTION TO BE AVERAGED WITH THE
              LOWER ROUNDS ON THE NETWOPK TO YIELD THE AVERAGE NETWORK
                                                                                777
C
              COMPLETION TIME DISTRIBUTION.
                                                                                778
C
```

A39

```
C
                                                                                   780
       IC=NINCL(IR)
                                                                                   781
       IR=2**NINCL(IR)
                                                                                   782
                                                                                   783
       IDDALL = 1 MEANS ALL ACTIVITY CONFIGURATIONS ARE EXPLICITLY
C
                CONSIDERED.
                                                                                   784
C
       IDCALL = C MEANS TO SAMPLE.
                                                                                   785
C
                                                                                   786
C
                                                                                   787
      IDOALL = 0
                                                                                   788
      IF (SAMSIZ.LF.C.OR.SAMSIZ.GE.IB) IDOALL=1
                                                                                   734
      M. I=1 SSSE OO
                                                                                   790
 3222 \text{ CTIME(I)} = \text{COT(I)}
                                                                                   791
      GO TO 20000
                                                                                   792
C
                                                                                   793
C
          STATEMENT 3204 IS THE RE-ENTRY POINT FROM THE SIMPLEX
                                                                                   794
                                                                                   795
C
          ALGORITHM WHEN CLUSTER BASED BOUNDS ARE BEING COMPUTED
C
                                                                                   796
      CONTINUE
3204
                                                                                   797
      DO 6032 I=1.10
                                                                                   798
      MOMENT(IR, I) = MOMENT(IR, I) + (BIINV(1, NMMP1) ** I) *SPROB
6032
                                                                                   799
9900
      X = B1INV(1.NMMP1)
                                                                                   800
      X=X-1.30-10
                                                                                   801
                                                                                   802
      I = 0
6420
                                                                                   803
      I = I + 1
      IF(x.GT.FD(I)) GO TO 6420
                                                                                   804
      NLEFD(IR.I)=NLEFD(IR.I)+SPPUB
                                                                                   805
10001 CONTINUE
                                                                                   806
20000 IP=IP+1
                                                                                   807
      NIB(IR)=NIB(IR)+1
                                                                                   808
                                                                                   809
C
          GENERATE NEXT ACTIVITY CONFIGURATION TO BE EXPLICITLY
                                                                                   810
          CONSTDERED.
                                                                                   811
C
                                                                                   812
      IF (IDDALL.EG.O) GO TO 20500
                                                                                   813
      IF (IP.GT.IB) GO TO 3207
                                                                                   814
      RANSAM = IP
                                                                                   815
      GO TO 20501
                                                                                   816
20500 IF(NIR(IP).GT.SAMSIZ) GO TO 3207
                                                                                   817
      IYUTS = IYUTS *65539
                                                                                   818
                                                                                   819
      TF (IYUTS) 6210,6211,6211
                                                                                   820
 6210 IYUTS = [YUTS+2147483647+1
 6211 XRAN = TYUTS
                                                                                   821
      XRAN = XRAN+.4656613F-9
                                                                                   822
      PANSAM = XRAN*DFLOAT(IB-1) + 1
                                                                                   823
                                                                                   824
20501 CONTINUE
                                                                                   825
C
      CONVERT THE PANDOM NUMBER: RANSAM: TO A BINARY NUMBER TO DEFINE AN
C
                                                                                   826
      ACTIVITY CONFIGURATION.
                                                                                   827
C
                                                                                   828
      KRAN = RANSAM
                                                                                   829
      SPROB=1.DO
                                                                                   830
      DD 8505 I=1.IC
                                                                                   631
      THALF = KRAN/2
                                                                                   8 32
                                                                                   933
      IZ = KRAN - IHALF*2
      L = INCLUS(IR.I)
                                                                                   934
      CTIME(L) = [Z*FHI(L)-IZ*FLO(L) + FLO(L)
                                                                                   935
      SPROB=SPROB+(1Z*PQ(L)+(1-IZ)*PP(L))*2.00
                                                                                   836
                                                                                   637
C
         SPROHE 2**NINCL(IR) * THE PROHABILITY OF THIS CONFIGURATION
                                                                                   538
```

r,

```
59
8505
      KRAN = [HALF
                                                                                    840
      CALL BINVA(62800)
                                                                                    841
3207
      NIR(IR)=NIR(IR)-1
                                                                                    842
      00 6030 1=1.10
                                                                                    843
      MOMENT(IR.I) = MOMENT(IR.I)/NIB(IR)
6030
                                                                                    844
      GO TO 3200
                                                                                    845
      WPITE (6.6362)
3208
                                                                                    846
6362
      FORMAT (1H1)
                                                                                    847
       IF (ICBCP.EQ.2) GO TO 6G11
                                                                                    848
      DO 10000 J=1.10
                                                                                    849
                                                                                   850
      I TMAX= 1
                                                                                   851
      TMAX=0 .
      DO. 5021 I=1,KCPB
                                                                                    852
                                                                                    853
      IF (NINCL(1).EQ.0) GO TO 5021
      IF (MOMENT(I,J).LF.TMAX) GO TO 5021
                                                                                    854
      TMAX = MCMENT(I.J)
                                                                                    855
                                                                                   856
      ITMAX=I
5021
      CONTINUE
                                                                                   857
                                                                                   858
      WPITE (6.5023) J.J.MOMENT(ITMAX.J)
      FORMAT (1H0.5X. "A LOWER BOUND: T+(":I2.";THFTA.LAMBDA): ON THE "
                                                                                   859
               12 . . - TH MOMENT OF THE NETWORK COMPLETION TIME = . E15.5)
                                                                                   860
10000 CONTINUE
                                                                                   861
                                                                                   862
C
                                                                                   863
C
          BEGIN THE PROCEDURE FOR DETERMINING UPPER BOUNDS ON THE
C
                                                                                   864
         NETWORK COMPLETION TIME DISTRIBUTION
                                                                                   865
                                                                                   866
C
                                                                                   867
9011
      CONTINUE
                                                                                   868
      DD 9007 TR=1.KCPB
      IF (NINCL (IR) . FQ . Q) GO TO 9007
                                                                                   869
                                                                                   870
      DO 9990 1=2.1EDF
                                                                                   871
      11 = 1 - 1
                                                                                   872
9990
      NLFFD(IR.I)=NLEFD(IR.I)+NLEFD(IR.II)
      WNNIR=DFLCAT(NIR(IR))
                                                                                   873
      DO 39990 I=1. IFDF
                                                                                   874
39990 NLEFD(IR.I)=NLEFD(IP.I)/WNNIB
                                                                                   875
                                                                                   876
9007
      CONTINUE
                                                                                   877
      DO 10111 IR=1,KCPB
      IF(NINCL(IR).GT.C) GO TO 10112
                                                                                   878
                                                                                   679
10111 CONTINUE
                                                                                   880
10112 IRR=IF
                                                                                   981
C
          IRR = NON-EMPTY CLUSTER WITH THE SMALLEST INDEX
C
                                                                                   882
                                                                                   983
C
      DO 10119 IR=1.KCPB
                                                                                   884
      IF(NINCL(IR).EQ.0) GO TO 10119
                                                                                   885
      DO 10117 I=1.IFDF
                                                                                   886
                                                                                   887
      IF(NLEFC(IR,I).LT.NLEFD(IRR,I)) NLEFD(IRR,I)=NLFFD(IR.I)
                                                                                   888
10110 CENTINUE
                                                                                   889
10119 CONTINUE
                                                                                   690
      WRITE (6,6264)
                                                                                   891
      WRITF(6.9423)
      FORMAT (1HO.5X. 'AN UPPER BOUND ON THE NETWORK COMPLETION TIME DISTR
                                                                                   892
9423
     * IRUTION: F+(.: THETA: LAMHDA)*)
                                                                                   693
                                                                                   894
      DO 9421 I=1, IEDF
      NSAVE( I )=NLEFD( IRR, I )
                                                                                   895
                                                                                   896
      X=NLEFD(TRR.I)
                                                                                   897
      WRITE(5.5422) FD(1).THETA.LAMBDA.X
9421
      FORMAY (17X, "F+(",F15.5; "; ".E15.5."; ".F15.5.") = ".E15.5)
                                                                                   818
9422
```

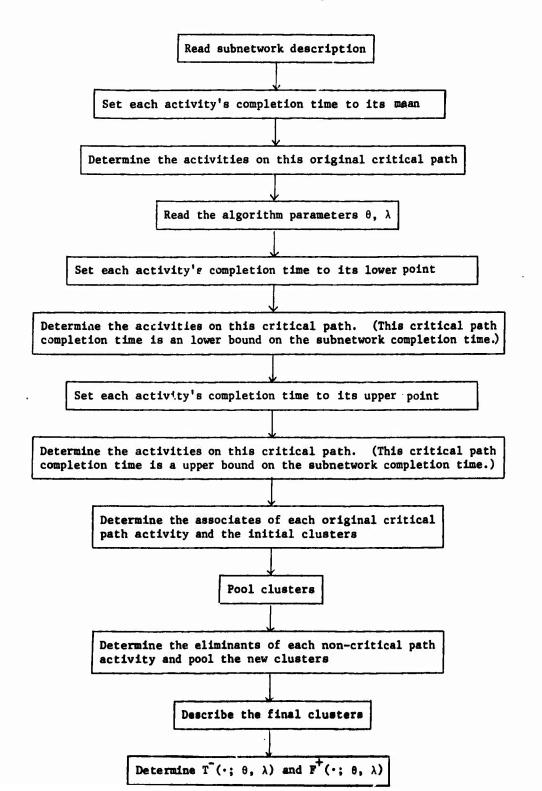
C

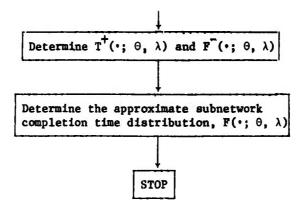
```
c
          BEGIN THE PROCEDURE FOR DETERMINING UPPER BOUNDS ON THE MOMENTS
                                                                                  900
^
          OF THE NETWORK COMPLETION TIME AND LOWER BOUNDS ON THE
                                                                                  901
         DISTRIBUTION OF THE COMPLETION TIMES.
                                                                                  902
                                                                                  903
                                                                                  904
          THE UPPER BOUNDS: T+(R-THETA-LAMBDA). ARE NOW DETERMINED.
                                                                                  905
                                                                                  906
C
                                                                                  907
C
                                                                                  908
                                                                                  ong
C
C
         FOR THE SAKE OF NUMERICAL ACCURACY THE PERT PROBLEM
                                                                                  910
         WITH NEW ACTIVITY TIMES IS INITIALLY SOLVED FROM SCRATCH
                                                                                  911
C
C
          INSTEAD OF UPDATING AN OLD SOLUTION.
                                                  AFTER THIS
                                                                                  912
C
         REINITIALIZATION. THE REMAINING CRITICAL PATH TIMES ARE
                                                                                  913
C
         DETERMINED BY UPDATING THIS SOLUTION.
                                                                                  914
C
                                                                                  915
C
                                                                                  916
      ICBCP= 1
                                                                                  917
      DO 6001 I=1.M
                                                                                  918
      CTIME(I)=FHI(I)
                                                                                  919
      COT(I)=FHI(I)
                                                                                  920
6001
                                                                                  921
      GO TO 6010
6011
      WRITE (6.6264)
                                                                                  922
6264
      FORMAT(///)
                                                                                  923
                                                                                  924
      DO 10009 J=1.10
      ITMIN=IRR
                                                                                  925
      TMIN=MCMENT(IRP.J)
                                                                                  926
      DO 7101 I=1.KCPB
                                                                                  927
      IF (NINCL(I ).EQ.0) GD TO 7101
                                                                                  928
                                                                                  929
      IF (MOMENT(I.J).GT.TMIN) GO TO 7101
                                                                                  930
      ITMIN= I
      TMIN=MCMENT(I.J)
                                                                                  931
7101
      CONTINUE
                                                                                  932
10009 WRITE (5.6012) J.J. MOMENT(ITMIN.J)
                                                                                  933
      FORMAT (1H0.5%.*AN UPPER BOUND, T+(*.I2.*;THETA.LAMBDA). ON THE *
                                                                                  934
6012
     *.I2. *- TH MOMENT OF THE NETWORK COMPLETION TIME = *.E15.5)
                                                                                  935
                                                                                  936
      DO 66900 TR=1.KCP3
      IF (NINCL (IR) . EQ. n) GO TO 66900
                                                                                  937
                                                                                  938
      DO 6900 I=2. IEDE
      II=I-1
                                                                                  939
6900
      NLEFD(IR.I)=NLFFD(IP.I)+NLEFD(IR.II)
                                                                                  940
      WNNTB=DFLOAT(NIB(IR))
                                                                                  941
      DO 49930 I=1. IEDF
                                                                                  942
49990 NLFFD([R.I)=NLEFD(IR.I)/WNNIB
                                                                                  943
                                                                                  944
66900 CONTINUE
      DO 20115 IR=1.KCPB
                                                                                  945
                                                                                  946
      IF(NINCL(IR).EQ.0) GO TO 20115
                                                                                  947
      DO 20110 I=1. IEDF
      IF(NLEFC(IR.I).GT.NLFFD(IRR.I)) NLEFD(IRR.I)=NLFFD(IR.I)
                                                                                  948
                                                                                  949
20110 CONTINUE
                                                                                  950
20115 CONTINUE
                                                                                  951
      WRITE (6.6362)
      WRITF(6.6423)
                                                                                  952
      FORMAT (1HO.5X. *A LOWER BOUND ON THE NETWORK COMPLETION TIME DISTR
                                                                                  953
     *IBUTION: F-(.; THETA: LAMBDA) )
                                                                                 954
                                                                                  955
      DO 6421 I=1.IEDF
                                                                                  956
      X=NLFFU(IRR,I)
      #PITE(5.6422) FD(1).THETA.LAMBDA.X
                                                                                  957
6421
                                                                                 958
      FORMAT(17x, *F-(*,F15.5, *; *,E15.5.*; *,E15.5.*) = *,E15.5)
6422
                                                                                 959
C
```

```
C
         THE APPROXIMATE NETWORK COMPLETION TIME DISTRIBUTION
                                                                               960
C
                                                                               961
      WRITE (6.6362)
                                                                               962
      WRITE(6,9472)
                                                                               963
9472
      FORMAT(1HO.5X. AN APPROXIMATE NETWORK COMPLETION TIME DISTRIBUTION
                                                                               964
     965
                                                                               966
     *ETA.LAMBDA) ) .//)
      DO 9471 I=1.1EDF
                                                                               967
      X=+5DC *NSAVE(I)
                           +.5D0*NLEFD(IRR.I)
                                                                               968
9471
      WFITF(6,9473) FD(1),THETA,LAMBDA,X
                                                                               969
      FORMAT(17x.* F(*,E15.5,*;*,E15.5.*;*,E15.5.*) = *,F15.5)
                                                                               970
9473
999
      WRITE(6,850)
                                                                               971
      STOP
                                                                               972
                                                                               973
      END
      SUBROUTINE BINVA(*)
                                                                               974
                                                                               975
      IMPLICIT REAL *8 (4-H+0-Z)
      COMMON BIINV.PFDCOS.CTIME,XB1.INBASF.IHFAD.ITAIL.NMMP1.NMM.N.ISTAT
                                                                               976
                                                                               977
      CONNEN M.MP1
      DIMENSION ISTAT(100), IHEAD(60), ITAIL(60), XB1(41)
                                                                               978
      DIMENSION 81INV(41.41). INBASE(40).CTIME(100).REDCOS(100)
                                                                               979
                                                                               980
         UPDATE THE FIRST ROW OF BIINV AFTER CHANGING CTIME
C
                                                                               981
                                                                               982
C
      DO 1 1=2. NMMP1
                                                                               983
      B1INV(1 \cdot I) = 0 \cdot 0
                                                                               984
                                                                               985
      DO 1 J=2. KMMP1
   -1 B11NV(1,1) = B11NV(1,1) + B11NV(J,1)*CTIME(INBASE(J-1))
                                                                               986
                                                                               987
Ç
C
         UPDATE VALUE OF THE OBJECTIVE FUNCTION
                                                                               988
C
                                                                               989
      XR1(1) = B1TNV(1,NMMP1)
                                                                               990
                                                                               991
      RETURN1
                                                                               992
      FND
      SURROUTINE BINV1 (*.TMNFW.TMOLD.ID)
                                                                               993
      IMPLICIT REAL *B (1-H,0-7)
                                                                               994
      COMMON BIINV, REDCOS, CTIME, XB1+INBASE+IHEAD+ITAIL+NMMP1+NMM+N+ISTAT
                                                                               995
                                                                               996
      COMMON M. MPI
      DIMENSION ISTAT (100) . IHEAD(60) . ITAIL (60) . XA1(41)
                                                                               997
                                                                               998
      DIMFNSION DIINV(41.41).INBASE(40).CTIME(100).REDCOS(100)
                                                                               999
C
        COMPUTE THE REDCOS CORRESPONDING TO ONE CHANGE IN CTIME
                                                                              1000
C
                                                                              1001
C
                                                                              1002
      DO 2 I=1.NMM
    2 IF(INBASE(1).EQ.ID) [ [= [+1]
                                                                              1003
                                                                              1004
      DIFF = TMNEW-TMOLD
         TMNEW IS THE NEW TIME AND TMOLD IS THE OLD TIME CORRESPONDING
                                                                              1005
                                                                              1006
         TO THE SINGLE CHANGE IN CTIME
                                                                              1007
                                                                              1008
     DO 1 K=1.M
                                                                              1009
      IF(ISTAT(K).EQ.1) GO TO 1
      REDCOS(K) = REDCOS(K) - DIFF + (BIINV(II + IMEAD(K) + I) -
                                                                              1010
                                                                              1011
        RIINV(II.ITAIL( K)+1))
    1 CONTINUE
                                                                              1012
                                                                              1013
      DC 3 K=MP1.N
                                                                              1014
      IF (ISTAT(K).EQ.1) GO TO 3
                                                                              1015
      REDCOS(K) = REDCOS(K) - DIFF*B1INV(II*K-M+1)
                                                                              1016
    3 CONTINUE
                                                                              1017
         UPDATE THE FIRST ROW OF BLINV AFTER CHANGING CTIME
                                                                              1018
```

	DO 10 I=2, NMMP1	1020
	B1INV(1,I)=31INV(1,I)+DIFF *B1INV(II,I)	1021
10	CONTINUE	1022
C		1023
C	UPDATE VALUE OF THE OBJECTIVE FUNCTION	1024
c		1025
	XB1(1) = B1INV(1.NMMP1)	1026
	RETURN1	1027
	END	1028

New Subnetwork Analysis Program: Flowchart





#### APPENDIX C

# Original Subnetwork Analysis Program

The Original Subnetwork Analysis Program is an implementation and extension of the analytical procedure described in Section 3 of Technical Report No. 48. The basic required input is

- (a) an acyclic network with one source and one sink,
- (b) two points from each component activity's completion time distribution, and
- (c) specified values for the algorithm parameters  $\boldsymbol{\theta}$  and  $\boldsymbol{\lambda}.$  The output is mainly
  - (a) upper and lower bounds on the moments of the network completion time,  $T_r^+(\theta, \lambda)$  and  $T_r^-(\theta, \lambda)$  r = 1, 2, ..., 10;
  - (b) upper and lower bounds on the distribution function of the network completion time,  $F^+(\cdot; \theta, \lambda)$  and  $F^-(\cdot; \theta, \lambda)$ ; and
  - (c) an approximate network completion time distribution,  $F(\cdot; \theta, \lambda) = 1/2[F^{\dagger}(\cdot; \theta, \lambda) + F^{\dagger}(\cdot; \theta, \lambda)].$

The main extension of this program is the inclusion of an option to consider only a random sample of the  $2^{n_c}$  activity time configurations for a cluster C instead of explicitly evaluating the critical path time for all of the  $2^{n_c}$  activity time configurations.

The basic computational technique for determining critical path times is the Simplex Algorithm. This algorithm is applied to the dual problem. The Simplex Algorithm is used instead of the standard network analysis techniques because the Simplex Algorithm is ideally suited for the type of parametric programming required to evaluate several critical path times when only the activity times vary from one problem to the next.

A listing of the Original Subnetwork Analysis Program and a program flowchart are given at the end of this appendix.

# Specific Input Instructions:

Card 1. Col. 1-3: The number of activities in the network, Format (I3).

Col. 4-6: The number of nodes in the network, Format (13).

For each activity one card with:

Col. 11-15: The origin node of the activity, Format (15).

Col. 21-25: The terminal node of the activity, Format (15).

Col. 31-40: The lower point on the activity's completion time distribution, Format (F10.0)

Col. 41-50: The upper point on the activity's completion time distribution, Format (F10.0)

Next Card. Col. 1: OPTON1. OPTON1=1 implies that the program will terminate after the clusters have been formed on the basis of associates and eliminants.

OPTON=1 implies that the program will follow the normal procedure.

Next Card. Col. 1-3: IEDF. The program computes an absolute upper and lower bound for the network completion time.

This range is subdivided into IEDF equal parts and the approximate distribution function (F<sup>+</sup>, F<sup>-</sup>, F) values are printed at each of these dividing points. IEDF would usually be between 10 and 100. IEDF, Format (I3).

Next Card. Col. 1-5:  $\theta$ , Format (F5.2).

Col. 6-10:  $\lambda$ , Format (F5.2)

Next Card. Col. 1-10: SAMSIZ. The number of activity time configurations to be randomly selected for explicit consideration in each cluster analysis. If SAMSIZ < 0 or SAMSIZ > 2 c, all activity time configurations will be explicitly considered - no random sampling will be done. Format (IlO).

The nodes should be numbered 1, 2, ..., n with the source being number 1, the sink being number n, and the other node numbers being arbitrary. The activities should be numbered 1, 2, ... in any order desired.

# Current Dimension Restrictions:

Currently the program is dimensioned for a maximum of

- 60 Activities
- 40 Nodes
- 25 Clusters
- 25 Activities/Cluster and IEDF < 500.

### Example:

The program's input and output are illustrated in terms of the network in Figure C-1.

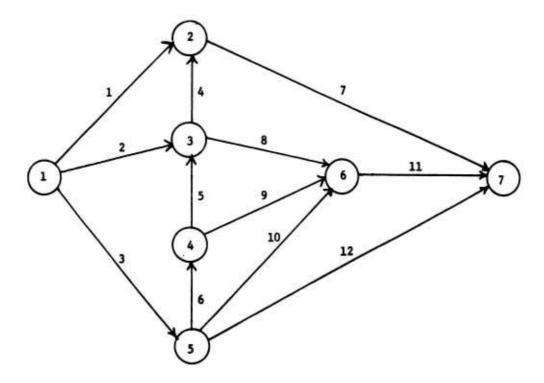


Figure C-1. Original Subnetwork Analysis Program Example Network

012007				
	1	2	17.26	19.44
	1	3	19.26	21.44
	1	5	12.76	15.91
	3	2	3.51	4.01
	4	3	3.01	5 . 4 3
	5	4	3.52	4.25
	2	7	13.75	14.48
	3	6	5.05	8.43
	4	6	5.36	6.51
	5	6	8.78	11.44
	6	7	15.76	17.21
	5	7	14.32	18.35

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# SAMPLE OUTPUT

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PERCENTILF DIFFERENCE											1.4500	
AVERAGE	18.3500	20.3500	14.3350	3,7600	4.2230	3.8850	14.1150	6.7450	5.9350	15.1100	16.4850	16.3350
UPPER PERC.	19.4439	21.4400	15.9130	4.0100	5.4300	4.2500	14.4800	8.4300	6.5100	11.4450	17,2100	18.3500
LOWER PFRC.	17.2690	19.2600	12.7000	3.5100	3.0100	3.5200	13.7500	5.0530	5.3600	8.7830	15. 7629	14.3200
TEPMINAL	0	n	c	8	m	•	^	9	·c	c	4	^
DRIGIN	-	-	-	m	•	r	۸	~	•	r	9	ın
ACTIVITY	-	N	'n	•	50	c	^	•	•	01	=	12

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C.45665D C2 THE CRITICAL DATH TIME WHEN EACH ACTIVITY'S COMPLETION TIME IS SET EQUAL TO ITS AVERAGE IS =

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Ď	5	1.	A LOWER BOUND. T-( 2:THFTA.LAMBDA). UN THF		Z		MOMENT	90	THE	NETWORK	2-TH MOMENT OF THE NFTWORK COMPLETION TIME	TIME	W	0.210.990 04	0
J.	CND.	1	A LOWFP ACUND, T-( 3;THFTA,LAMACA), ON THE	:	I F		HOMENT	90	H	NETWORK	3-TH MOMENT OF THE NETWORK COMPLETION TIME	TIME	n e	0.97664D 05	S C
90	eno.	7	A LOWER BOUND. T-( 4:THSTA.LAMBDA). ON THE 4-TH MOMENT OF THE NETWORK COMPLETION TIME		I F	H 6-1H	TARENOW.	OF	H	NETHORK	CJMPLETION	11 ME	u)	0.447420 07	0
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ř	CND.	1-1	A LOWER SCUND, T-( 6:THETA.LAMSDA), ON THE	0 :	Ĭ .		TRANCH	Ŗ	H H	NETWORK	6-TH MOMENT OF THE NETWORK COMPLETION TIME	TIME		0.954940 10	0
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F-(	0.412130	: 20	r.100000 31	31:	0.100000-011	513	Ħ	0.312500-01	-
)-5	0.417700	: 20	0.100000	: 1:	2.100200	610	fi.	C-468750-01	=
) - L	0.423260	02;	0-10C00D	:: '	6.160000	-		0.937500-01	=
7-8	0.429830	02:	6.190300	:10	0.10000	610	H	0.125000	0
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) <u>- 1</u>	0.456650	. 20	0.100050	:10	0.100000	C13	H	0.459750	0
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۴- (	0.490640	52:	C-100ccD	61:	C. 100000	13	ıŧ	0.875000	0
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THE FOLLOWING TABLE WAS COMPUTED CONSIDERING ALL PERCENTILE COMBINATIONS.

N UPPER	S BCUND	2	THE N	ETVO	FK C	OPPLET IC	1	INE DI	AN UPPER BOUND ON THE NETWORK COMPLETION TIME DISTRIBUTION: F+(.;THETA;LAMBDA	 	+		ETA ; LAMBD	?
	)+u		0.406570	570	(2:	0.100000	opac	01:	C. 1C00CD		(1)	μ	0-156250-0	0-0
	ĭ		9.412130	130	62:	C-1000CD	0366	01:	0.10353D			#	C-31250D-0	0-0
	F+(	•	9.4177CD		023	C.10C30D	0000	01:	9-11-2000	0	1	ė.	0.469750-01	0-0
	1+4		9.423260	260	22.	0,100000	0000	:1:	3-100000	C	-		0.937503-01	0-0
	44		C.424830	8.30	:23	C-10CCC9	6300	31:	3. 1000 30	0		ı	0.125000	õ
	F+(		0-434390	340	: 23	C. 1000CD	CODE	:16	0.100000	0	-	н	C-1875C9	000
	1+4		0-439960		C2:	0.100000	0950	:10	3.10000		610	H	0.296880	ŏ
	F+(		9.445520	520	62:	0.100300	0000	::	0.10000	0	1		0.312500	0
	-		0.451690	963	623	C-100cCD	6000	:10	0.10000	0	-	ti	0.391639	0
	1		C.45665D	650	C2:	0.100300	9000	110	9.10000		(1)	11	0.468750	ŏ
	¥.		9.462210	210	62:	0-100100	0000		0.10000	٥	1	11	0.531250	õ
	1+4		0.467780	780	.20	0.10000	JCn	:10	3.10000	c	1	н	0.625000	0
	F+(		0.473340	340	62:	C-10Creb	200	: 13	G-10001D	c	2	н	0.647500	0
	F+(		2.478310	č	C2:	C.1036CD	9000	٠ı:	C. 1C9CCD	0	-	H	0.791250	č
	1+4		0.484470	470	:26	0.100200	0000		0.100000	0	1	H	0.343750	ŏ
	F+(		0.490040	040	22:	0.100000	0000	:16	C. 10000D		(1)	н	C.97500D	0
	F+(		0.4954ch	Sen.		C.10C0CD	Goo	:1:	0.00011.0	0	51)	11	C-99625D	õ
	**		9.501170	2	625	C-1000CD	Qu'ii	:10	00-100-0	0	C13	#	C. 137500	0
	F+(		9.506730		02:	0.10000	0000	91:	0,100000 111	0	_	H	0.964750	õ
	146		0.5123CD C2:	300		110 00133170	000		612 62027120	0	-		0-196660	0

AN APPOCATMATE NETWORK COMPLETION TIME DISTRIBUTION:

F-(.:THETA.LAMBCA) )
٠
( F+(.;THETA,LAMBCA)
*
ıc.
٥.
F(.:THETA.LANBDA

- 0	5	10-	5	00	00	00	000	00	00	C	0	00	00	00	00	00	60	00	10	
0-156259-01	0-3125cD-0	0-468759-0	C-9375CD-C	0.125C0D	0.147569	0.296880	6.312500	0.330639	0.408750	0.531250	0.625000	0.58750D	0.73125D	0.443750	0.975500	0.936250	0.937500	0.568750	000001-6	
Ц	н	11		1)	11	н	H	11	11	þ	II	ļi	н	н	ıı	H	16	н	ĮI	
(1)	000	613	E	0.10	010	10	C1.		(1)	-	C10	010	5	(1)	013	C13	3	3	3	
0.100000	0.100000	0.10000	0-100000	C-10000	0.10000	0.100000	0.100000	0-170000	0.100000	3.117000	0-100000	0.10030	3.102000	J. 10000D	2-100000	00000100	9.10copp	0.100010	3, 100300	
01:	. 10	01:		:16	: 10	: 10	:10	:1:	01:	: 1 :	:10	:10	:10	. 16	.10	01:	91:	:10	: 10	
0.100000	0.100000	0.100000	C. 19000D	0.10cccD	9.100ccn	0.100000	0.100100	0.100000	0-100000	C.1000CD	0.10000	0.100300	0-100000	C-10CcC5	0.100000	0.100000	0.100000	0-100000	0.100000	
02:	: 20		.50	: 20	65:	62:	05:	 C2:	. 20	: 22	72:	: 63	: 20	C2:	95:	62:	. 20	05:	: 60	
0.406570	2.412130	3-417700	9.42326D	0.4248.30	3.434390	0.439960	0-445520	0.451090	0.456650	0.462210	9-467780	0.473340	0.478910	9-4844 70	0.49004D	0.495600	2.501170	9.506730	0.512300	
ĭ	ŭ	F.	F	ĭ	Ē	è	ī	ŭ	ĭ	Ĩ.	ĭ	ŭ	ŭ	Ĕ	ĭ	ŭ	Ĕ	ĭ	ĭ	

### PROGRAM LISTING

```
C
                                                                                      1
 C
           ORIGINAL SUBNETWORK ANALYSIS PROGRAM
                                                                                      2
 C
                                                                                      3
       IMPLICIT REAL *8 (A-H.O-Z)
           FOR THE SAKE OF IDENTIFYING THE APPROPRIATE DIMENSIONS. LET
 C
                                                                                      5
 C
                M = THE NUMBER OF ACTIVITIES IN THE NETWORK
                                                                                      6
                                                                                      7
 C
                NMM = NUMBER OF NODES IN THE NETWORK
 C
                NMMP1 = NMM + 1
                                                                                      8
 C
                N = M + NMM
 C
                L = THE LENGTH OF THE CRITICAL PATH
                                                                                     10
 C
                C = THE MAXIMUM NUMBER OF BRANCHES IN A CLUSTER
                                                                                     11
 C
                IEDF = THE NUMBER OF DIVISIONS IN THE EMPIRICAL
                                                                                     12
                       DISTRIBUTION FUNCTION
 C
                                                                                     13
 C
                                                                                     14
                                                                                     15
 C
       INTEGER TAIL( M).HEAD( M).ASSGRP( L.L ).CLINCL(L.L).EGRP(L)
                                                                                     16
       DIMENSION NINCL( C). INCLUS( L. C). NCLINC( L)
 C
                                                                                     17
 С
       DIMENSION NLEFD(IEDF), FD(IEDF), NSAVE (IEDF)
                                                                                     18
                                                                                     19
 C
       DIMENSION IZZ( C).AVG( L).THAT(L)
 C
                                                                                     20
       DIMENSION INBASE (NMM), XNODE (NMM)
 C
       DIMENSION LEFT(M ).LEFTO(M ).NONCP(M)
                                                                                     21
 C
       DIMENSION XB1 (NMMP1), Y1 (NMMP1), REDCOS(N), ISTAT(N)
                                                                                     22
 C
       DIMENSION ICRITP(L) .NINAG(M) .ICRITN(L+1) .CTIME(N) .COT(N)
                                                                                     23
 C
       DIMENSION KB(L), IBB(L), F25(M), F75(M), SIGMA(M), B1INV(NMMP1, NMMP1)
                                                                                     24
· C
       REAL
                     MCMENT (L.10)
                                                                                     25
 C
                                                                                     26
                                                                                     27
 C
          OF COURSE THESE DIMENSIONS ARE MERELY UPPER BOUNDS
. C
                                                                                     28
                                                                                     29
 C
       COMMON BIINV.REDCOS.CTIME.XB1.INBASE.HEAD.TAIL.NMMP1.NMM.N.ISTAT
                                                                                     30
       COMMON M.MPI
                                                                                     31
       INTEGER TAIL(60), HEAD(60), ASSGRP(25, 25), CLINCL(25, 25), EGRP(25)
                                                                                     32
                                                                                     33
       INTEGER SAMSIZ.RANSAM
       DIMENSICH MINCL (25), INCLUS (25, 25), NCL INC (25)
                                                                                     34
                                                                                     35
       DIMENSION FD(500).NLEFD(500).NSAVE(500)
                                                                                     36
       DIMENSION AVG(25) THAT(25)
                                                                                     37
       DIMENSICH INBASE (40)
                                                                                     38
       DIMENSION XNODE(40)
       DIMENSION X81(41).Y1(41).REDCOS(100).ISTAT(100)
                                                                                     39
                                                                                     40
       DIMENSION BIINV(41,41), KB(25), IBB(25), FLO(60), FHI(60), SIGMA(60)
       DIMENSION ICRITP(25), NINAG(50). ICRITN(26). COT(100). CTIME(100)
                                                                                     41
       DIMENSION LEFT (60), LEFTO (60), NONCP (60)
                                                                                     42
       REAL*8 LAMBDA.MOMENT(25,10)
                                                                                     43
                                                                                     44
          M = THE NUMBER OF ACTIVITIES IN THE NETWORK
C
          NMM = THE NUMBER OF NODES IN THE PERT NETWORK
                                                                                     45
C
                                                                                     46
       READ(5.100)
                     M. NMM
                                                                                     47
100
       FORMAT(213)
       N=NMM+M
                                                                                     48
                                                                                     49
       MP1=M+1
                                                                                     50
       NMMP1=NMM+1
                                                                                     51
C
          THE ACTIVITIES ARE DESCRIBED IN TERMS OF THEIR NODES
C
                                                                                     52
. C
          II=THE TAIL NODE. THE ORIGIN NODE
                                                                                     53
          JJ=THE HEAD NODE, THE TERMINAL NODE
C
                                                                                     54
          FLO = THE LOWER PERCENTILE
                                                                                     55
C
. C
          FHI =
                  THE UPPER PERCENTILE
                                                                                     56
                                                                                     57
C
          SIGMA = FLO - FHI
                                                                                     56
C
```

DO 610 T=1.M

```
READ(5,2501) II, JJ. FLO(I ), FHI(I )
                                                                                 60
       SIGMA(I) = FHI(I)-FLO(I)
                                                                                 61
2501
       FORMAT(10x.15.5x.15. 5x.F10.0.F10.0)
                                                                                62
       COT(1) = (FLO(1) + FHI(1))/2.
                                                                                63
       CTIME(I) = COT(I)
                                                                                64
       TAIL(I) = II
                                                                                65
   610 HEAD(1)=JJ
                                                                                66
          COTEMA
                   = THE ORIGINAL RIGHT HAND SIDES. I.E. THE AVERAGE
                                                                                67
 C
 C
          OF FLO AND FHI
                                                                                68
       DO 55610 I=MP1.N
                                                                                69
 55610 CTIMF(I) = 0.
                                                                                70
                                                                                71
 C
               OPTINA =1 IMPLIES THAT THE PROGRAM WILL TERMINATE AFTER
                                                                                72
 C
                         THE CLUSTERS HAVE BEEN FORMED. NO BOUNDS ON
                                                                                73
                                                                                74
 C
                         THE PROJECT COMPLETION TIME MCMENTS OR
 C
                         DISTRIBUTION WILL BE DETERMINED.
                                                                                75
                                                                                76
 C
                       NOT = 1 IMPLIES THAT THE NORMAL PROCEDURE WILL BE
               OPTONI
 C
                         FOLLOWED.
                                                                                77
 C
                                                                                78
                                                                                79
       READ(5,77551) OPTON1
 77551 FORMAT(1011)
                                                                                80
       IF(OPTON1 .EQ.1) WRITE(6.77552)
                                                                                81
 77552 FORMAT(1H1:10X: OPTIONI=1 AND THE PROGRAM WILL TERMINATE AFTER THE
                                                                                82
      83
                                                                                84
      *ETION TIME MOMENTS OR DISTRIBUTION WILL BE DETERMINED. ..
                                                                                85
       READ(5,100) IEDE
       WRITE(6,2700)
                                                                                86
 2700 FORMAT(1H1.15X. INITIAL INPUT*)
                                                                                87
                                                                                88
       WRITF(6.2701)
      FORMAT(1HO,1CX, ACTIVITY ORIGIN TERMINAL LOWER PERC. UPPER P
                                                                                89
 2701
      *ERC.
               AVERAGE PERCENTILE DIFFERENCE! )
                                                                                90
                                                                                91
       DO 2704 I=1.M
       WPITF(6,2702) I.TAIL(1).HEAD(1).FLQ(1).FHI(1).CTIME(1).SIGMA(1)
                                                                                92
 2704
 2702 FORMAT(IH ,13X,13.5X,13.7X,13.5X,F10.4.3X,F10.4.3X,F10.4.4X,F10.4)
                                                                                93
                                                                                94
                                                                                95
 C
          THE FOLLOWING INDICATORS ARE USED:
                                                                                96
 C
                                                                                97
 •
                     IMPLIES THE CRITICAL PATH TIME WHEN ALL ACTIVITY
C
          IPARM = 1
                                                                                QR
                                                                                99
                     COMPLETION TIMES ARE SET EQUAL TO THEIR AVERAGES IS
·C
                     BEING DETERMINED
                                                                               100
C
                     IMPLIES THAT THE LOWER BOUND ON THE COMPLETION TIME
                                                                               101
C
          IPARM = 2
. C
                      FOR THE SUBNETWORK IS BEING DETERMINED
                                                                               102
                     IMPLIES THAT THE UPPER BOUND ON THE COMPLETION TIME
                                                                               103
 C
          IPARM = 3
 C
                      FOR THE SUBNETWORK IS BEING DETERMINED
                                                                               104
                    WHEN INDEXL=0 IMPLIES THAT THE ASSOCIATES ARE
                                                                               105
 C
          IPARM > 3
                                                                               106
C
                     BEING DETERMINED
                                                                               107
C
                                                                               108
C
                   IMPLIES THAT INITIAL CLUSTERS ARE STILL BEING FORMED
          INDEXL=0
                                                                               109
C
                    IMPLIES THAT THE LEFTOVERS. THEIR ELIMINANTS, AND
                                                                               110
          INDEXL=1
C
                          POOLED CLUSTERS ARE BEING DETERMINED
                                                                               111
C
                    IMPLIES THAT THE 2**NINCL( ) RUNS FOR EACH CLUSTER
C
          INDEXL=2
                                                                               112
                    ARE BEING MADE AND AVERAGED
                                                                               113
٠.
C
C
                                                                               115
          ICRCP = 0 IMPLIES THAT THE PROCEDURE FOR DETERMINING UPPER
                                                                               116
.c
                    BOUNDS ON THE MOMENTS OF THE NETWORK COMPLETION TIME
                                                                               117
C
                    AND LOWER BOUNDS ON THE DISTRIBUTION OF COMPLETION
                                                                               118
C
                                                                               119
C.
                    TIMES HAS NOT BEEN BEGUN
```

```
C
           ICBCP = 1 IMPLIES THAT THE PROCEDURE FOR DETERMINING UPPER
                                                                                    120
C
                     BOUNDS ON THE MOMENTS OF THE NETWORK COMPLETION TIME
                                                                                    121
C
                     AND LOWER BOUNDS ON THE DISTRIBUTION OF COMPLETION
                                                                                    122
C
                     TIMES IS BEING INITIALIZED
                                                                                    123
C
          ICBCP = 2 IMPLIES THAT THE PROCEDURF FOR DETERMINING UPPER
                                                                                    124
                     BOUNDS ON THE MOMENTS OF THE NETWORK COMPLETION TIME
C
                                                                                    125
C
                     AND LOWER BOUNDS ON THE DISTRIBUTION OF COMPLETION
                                                                                    126
C
                     TIMES IS BEING CARRIED OUT
                                                                                    127
C
                                                                                   128
C
                                                                                    129
C.
                      INPLIES THAT THE PROCEDURE FOR DETERMINING A UPPER
          IDLB = 0
                                                                                   130
C
               BOUND ON THE NETWORK COMPLETION TIME DISTRIBUTION HAS NOT
                                                                                   131
C
               REGUN
                                                                                   132
C
                      IMPLIES THAT THE UPPER BOUND ON THE NETWORK
          IDLB = 1
                                                                                    133
               COMPLETION TIME DISTRIBUTION IS BEING DETERMINED
C
                                                                                   134
                                                                                   135
       TPARM=1
                                                                                   136
                                                                                   137
       INDEXL = 2
       ICBCP=0
                                                                                   138
                                                                                   139
       IDLB = 0
6010
       CONTINUE
                                                                                   140
       20 104 I=1.NMM
                                                                                   141
   1C4 INRASE(I)=M+1
                                                                                   142
       DO 2001 J=1.M
                                                                                   143
2001
       ISTAT(J)=0.
                                                                                   144
                                                                                   145
       DO 2002 J=MP1.N
2002
       ISTAT(J)=1
                                                                                   146
                                                                                   147
       DO 10 IT=1.NMMP1
       DO 12 L=1.NMMP1
                                                                                   148
                                                                                   149
    12 BIINV(L.II) = 0.
    10 Blinv(II.II) = 1.
                                                                                   150
                                                                                   151
       DO 30 I=1.NMM
    30 XH1(I) = 0.
                                                                                   152
       XB1(NMMP1) = 1.
                                                                                   153
       TOLR1=1.00-10
                                                                                   154
                                                                                   155
C
C
          START THE SIMPLEX ALGORITHM
                                                                                   156
C
          SOLVE THE DUAL PROBLEM
                                                                                   157
           THE NUMBER OF VARIABLES IS M REAL + NMM SLACKS
                                                                                   158
C
           FOR A TOTAL OF N VARIABLES
                                                                                   159
- C
                                                                                   160
350
       CONTINUE
                                                                                   161
. 2800 DO 23 J=1.N
                                                                                   165
       RATS = 0.
                                                                                   163
       IF (ISTAT(J).EQ.1) GD TO 52800
                                                                                   164
       IF (J.GT.M) GO TO 22
                                                                                   165
       RATS =-B1INV(1.HEAD(J)+1)+B1INV(1.TAIL(J)+1) + CT[MF(J)
                                                                                   166
                                                                                   167
       GO TO 52800
   22 RATS =-B1 INV(1, J-M+1)
                                                                                   168
                                                                                   169
52800 RFDCOS(J)= RATS
                                                                                   170
   23 CONTINUE
                                                                                   171
22800 CONTINUE
                                                                                   172
       I RMAX=1
                                                                                   173
       RMAX=RFCCOS(1)
                                                                                   174
       DD 24 J=2.N
                                                                                   175
       [F(REDCOS(J) .LF. RMAX) GO TO 24
                                                                                   176
       RMAX=REDCOS(J)
                                                                                   177
       TRMAX=J
                                                                                   178
       CONTINUE
                                                                                   179
       IF(RMAX .LF. TOLR1) GO TO 401
```

```
82
 22824 CONTINUE
                                                                                     180
        DO 26 L=1.NMMP1
                                                                                     181
        IF (IRMAX.GT.M) GO TO 50026
                                                                                     182
                                                                                     183
        Y1(L) =-B1[NV(L.TAIL(IRMAX)+1)+B1[NV/L.HEAD(IRMAX)+1)
                                                                                     184
        GO TO 25
 50026 Y1(L) = B1 INV(L. IRMAX-M+1)
                                                                                     185
    26 CONTINUE
                                                                                     186
        Y1(1) = Y1(1) - CTIME(IRMAX)
                                                                                     187
                                                                                     188
        NUMBER=0
        DO 27 L = 2. NMMP1
                                                                                     189
 27
                                                                                     190
        IF(YI(L) .LE. TOLRI)
                                NUMBER=NUMBER+1
                                                                                     191
        IF(NUMBER .EQ. NMM) GO TO 403
                                                                                     192
        RMIN=. 99D 20
                                                                                     193
        IRMIN=0.
        DO 32 II=2.NMMP1
                                                                                     194
                                                                                     195
        IF(Y1(II).LE. TOLRI)
                               GO TO 32
        RATS = XB1([I]/Y1(II)
                                                                                    196
                                                                                    197
        RR=RATS-FMIN
                                                                                     198
        IF (PR .GE. 0.00) GU TO 32
                                                                                    199
        RMIN=PATS
                                                                                    200
        IRMIN=II
        CONTINUE
                                                                                    201
 32
                                                                                    202
        19MMM+S=L EE OD
                                                                                    203
        WW=811NV(IRMIN .J)/Y1(IRMIN )
                                                                                    204
       DO 37 L=1.NMMP1
                                                                                    205
. 37
        81[NV(L,J)=81[NV(L,J)-WW*Y1(L)
                                                                                    206
 33
        WW=(L. NIMNI)VNII8
 C
                                                                                    207
· C
           UPDATE THE BASIC VARIABLES: INBASE AND XB1
                                                                                    208
                                                                                    209
 c
                                                                                    210
        ISTAT(INBASE(IRMIN-1))=^
                                        COPY AVAILABLE TO DDC DOES NOT
                                                                                    211
        ISTAT(IRMAY)=1
        INBASE (IRMIN-1)=IRMAX
                                                                                    212
                                        PERMIT FULLY LEGIBLE PRODUCTION
                                                                                    213
        w=xB1(IRMIN )/Y1(IRMIN )
                                                                                    214
        DO 38 I=1.6MMP1
                                                                                    215
        XB1(I) = XB1(I) - Y1(I) + W
 38
       XB1 (IRMIN )=W
                                                                                    216
                                                                                    217
       GO TO 350
                                                                                    218
 403
       WRITE(6,530)
       FORMAT(1H0.5X. *NO FEASIBLE SOLUTION EXISTS. CHECK YOUR INPUT DATA
                                                                                    219
- 530
                                                                                    220
      *. *)
       WRITE(6,850)
                                                                                    221
                                                                                    222
       FORMAT (1H1)
. 850
       GO TO 999
                                                                                    223
                                                                                    224
C.
                                                                                    225
 C
           END OF THE SIMPLEX ALGORITHM
                                                                                    226
 C
                                                                                    227
       CONTINUE
 401
                                                                                    228
 •
                                                                                    229
           KKK= THE NUMBER OF NODES ON THE CRITICAL PATH
 C
           KR(L)= THE L-TH NODE IN THE CRITICAL PATH. COUNTING BACKWARDS
                                                                                    230
 C
                                                                                    231
                       FROM THE TERMINAL NODE
C
 C
           KKB= THE NUMBER OF ACTIVITIES ON THE CRITICAL PATH
                                                                                    232
           IBB(L) = THE L+TH ACTIVITY ON THE CRITICAL PATH. COUNTING
                                                                                    233
C
                                                                                    234
                        BACKWARDS FROM THE TERMINAL NODE
C
                                                                                    235
 C
                                                                                    236
       1F(1CBCP.EQ.1) GO TO 6008
                                                                                    237
        IF(INDEXL.EQ.2) GO TO 3204
                                                                                    238
           INHASE IS A SET OF M INTEGER VARIABLES WHICH INDICATE THE
                                                                                    239
```

```
COMPOSITION OF THE CURRENT BASIS. FOR EXAMPLE.
 C
                                                                                   240
 C
                               IMPLIES THAT THE K-TH COLUMN IN THE BASIS B
                INHASE(K) = 7
                                                                                  241
 C
                               CORRESPONDS TO THE 7-TH VARIABLE
                                                                                  242
 (
                                                                                  243
 C
                                                                                  244
 C
          ISTAT INDICATES THE BASIC STATUS OF EACH VARIABLE
                                                                                  245
 C
                              IMPLIES THAT THE K-TH VARIABLE IS IN THE
                ISTAT(K) = 1
                                                                                  246
C
                              DUAL BASIS
                                                                                  247
C
                              IMPLIES THAT THE K-TH VARIABLE IS NOT IN THE
                ISTAT(K) = 0
                                                                                  248
C
                              DUAL BASIS
                                                                                  249
C
                                                                                  250
C
                                                                                  251
C
          THE FOLLOWING STATEMENTS DETERMINE THE NODES AND ACTIVITIES ON
                                                                                  252
C
          THE CRITICAL PATH
                                                                                  253
 C
                                                                                  254
C
                                                                                  255
          THE DUAL SOLUTION IMPLIES THE FOLLOWING OPTIMAL SOLUTION TO THE
                                                                                  256
          PRIMAL PERT PROBLEM. HOWEVER SOME OF THE NODE TIMESCOTHER THAN
C
                                                                                  257
          THE LAST ONE) MAY BE HIGHER THAN NECESSARY. THUS IN
C
                                                                                  258
          DETERMINING THE CRITICAL PATH AN ALTERNATIVE OPTIMAL SOLUTION
                                                                                  259
C
C
          MAY HAVE TO BE IDENTIFIED.
                                                                                  260
C
          BLINV IS NOT CHANGED.
                                                                                  261
                                                                                  262
       DO 83002 I=1.NMM
                                                                                  263
83002 XNODE(I)=B1[NV(1.I+1)
                                                                                  264
       KKK=1
                                                                                  265
       KR(1)=NMM
                                                                                  266
83001 IK=KB(KKK)
                                                                                  267
                                                                                  268
. С
          DETERMINE WHETHER THE TIME TO REACH NODE IK
C
                                                             IS NECESSARILY
                                                                                  269
          AS LARGE AS INDICATED FROM THE DUAL SOLUTION
                                                                                  270
C
C
                                                                                  271
       SMIN=999999.
                                                                                  272
                                                                                  273
       ISMIN=0
       DO 83000 T=1.M
                                                                                  274
       IF(HEAD(I).NE.IK) GO TO 83000
                                                                                  275
       SLACK=XNODE(HEAD(I))-XNODE(TAIL(I))-CTIME(I)
                                                                                  276
       IF(SLACK.GE.SMIN) GO TO 83000
                                                                                  277
                                                                                  278
       SMIN=SLACK
       ISMIN=I
                                                                                  279
83000 CONTINUE
                                                                                  280
       [F(SMIN.LT.0.0001) GD TO 83003
                                                                                  261
                                                                                  282
C,C
          THE TIME FOR NODE IK WAS UNNECCESSARILY LARGE
                                                                                  283
C
C
                                                                                  284
       XNCDE(IK)=XNODE(IK)-SMIN
                                                                                  285
                                                                                  286
       KKK=KKK-1
                                                                                  287
       GO TO 93001
                                                                                  288
83203 IBB(KKK)=ISMIN
                                                                                  289
       KKK=KKK+1
                                                                                  290
       KB(KKK)=TAIL(ISMIN)
       IF(TAIL(ISMIN).GT.1) GO TO 83001
                                                                                  291
                                                                                  292
       KKB=KKK-1
       IF(INDEXL.EQ.1) GO TO 3121
                                                                                  293
                                                                                  294
       IPAPM=IPARM+1
       IF(TPARM.GT.4) GO TO 2910
                                                                                  295
       IF(IPARM.EQ.3) GO TO 6400
                                                                                  296
                                                                                  297
       IF (IPARM.EQ.4) GO TO 6401
                                                                                  298
          ICRITP(L)= THE L-TH ACTIVITY ON THE OPIGINAL CRITICAL PATH
C
                                                                                  299
```

```
C
           KCPB= THE NUMBER OF ACTIVITIES ON THE ORIGINAL CRITICAL PATH
                                                                                  300
                                                                                 301
C
                                                                                 302
       TOTAL = BIINV(1,NMMP1)
                                                                                 303
       KCPB=KKB
       ICFITN(1) = NMM
                                                                                 304
                                                                                 305
       DO 2802 I=1.KCPB
                                                                                 306
       ICRITN(I+1) = KB(I+1)
                                                                                 307
2802
       ICRITP([)=[BB(I)
       X=TOTAL
                                                                                 308
                                                                                 309
       WRITE(6,851) X
       FORMAT (1H0.5%, THE CRITICAL PATH TIME WHEN EACH ACTIVITY S COMPLE
                                                                                 310
 851
      *TION TIME IS SET EQUAL TO ITS AVERAGE IS = *.E15.5)
                                                                                 311
                                                                                 312
       WRITE(6,7606) KKK
                                                                                 313
  7606 FORMAT(1H0+10X++THE 1+13+ NODES ON THE CRITICAL PATH ARE AS FOLLO
                                                                                 314
      *WS BEGINNING WITH THE TERMINAL NODE: 1)
       WRITE(6,7707) (KB(I), I=1,KKK)
                                                                                 315
  7707 FORMAT(15x,20(13,*,*))
                                                                                 316
                                                                                 317
       WRITE(6,7710) KKB
7710 FORMAT (1HO.1CX. THE 1,13. CRITICAL ACTIVITIES ARE AS FOLLOWS BEGI
                                                                                 318
                                                                                 319
      *NNING WITH THE TERMINAL ACTIVITY: 1)
                                                                                 320
       WRITE(6.7707) (IBB(I).I=1.KKB)
       READ(5,2920) THETA, LAMBDA
                                                                                 321
2920
        FORMAT (2F5.2)
                                                                                 322
       WRITE(6.3071) THETA, LAMBDA
                                                                                 323
                                                                                 324
       FORMAT(1H0,10X, THETA = +,E15.5.+
                                              LAMBDA = '.E15.5)
3071
                                                                                 325
c
          SAMSIZ = THE NUMBER OF ACTIVITY TIME CONFIGURATIONS TO BE
C
                                                                                 326
                   RANDOMLY SELECTED FOR CONSIDERATION IN EACH CLUSTER
                                                                                 327
C
                                                                                 328
C
              SINCE THIS IS A RANDOM SAMPLE . SOME PERCENTILE
                                                                                 329
C
                                                                                 330
              COMBINATIONS MAY BE CONSIDERED MORE THAN ONCE.
C
                                                                                 331
                                                                                 332
       READ (5.3209) SAMSIZ
 3209 FORMAT (110)
                                                                                 333
                                                                                 334
C
          THE COMPLETION TIME FOR ALL ACTIVITIES IS SET TO THEIR LOWER
                                                                                 335
C
          PERCENTILE. THE RESULTING CRITICAL PATH TIME IS A LOWER
                                                                                 336
C
                                                                                 337
          BOUND ON THE EXPECTED CRITICAL PATH TIME.
C
                                                                                 338
C
                                      COPY AVAILABLE TO DDC DOES NOT
                                                                                 339
       DO 6402 T=1.M
 6402 CTIME(1) = FLO(1)
                                                                                 340
                                      PERMIT FULLY LEGIBLE PRODUCTION
                                                                                 341
       CALL BINVA(628CO)
       CPLB= BIINV(1.NMMP1)
                                                                                 342
-64CC
                                                                                 343
       WRITE(6.6405) CPLA
6405 FORMAT(1H0.5X. A LOWER BOUND ON THE EXPECTED CRITICAL PATH TIME IS
                                                                                 344
                                                                                 345
      * = .F15.5
                                                                                 346
       WRITE(6,7606) KKK
       WRITE(6,7707) (KB(I),I=1,KKK)
                                                                                 347
                                                                                 348
       WRITE(6,7710) KKB
       WRITE(6,7707) (IBB(1),1=1,KKB)
                                                                                 349
                                                                                 350
          THE COMPLETION TIME FOR ALL ACTIVITIES IS SET TO THEIR UPPER
                                                                                 351
          PERCENTILE. THE RESULTING CRITICAL PATH TIME IS A UPPER
                                                                                 352
C
                                                                                 353
          BOUND IN THE EXPECTED CRITICAL PATH TIME.
-C
                                                                                 354
C
                                                                                 355
       DO 6406 I=1.M
                                                                                 356
 6406 CTIME(I) = FHI(I)
                                                                                 357
       CALL BINVA(62800)
 6401 CPUR= 31 INV (1 . NMMP1)
                                                                                 358
```

WRITE(6.6409) CPUR

```
6409
       FORMAT (1H0.5X. "A UPPER BOUND ON THE EXPECTED CRITICAL PATH TIME IS
                                                                                   360
      * = ... F15.5
                                                                                   361
       WRITE(6,7606) KKK
                                                                                   362
                                                                                   363
       WRITE(6,7707) (KB(I).I=1.KKK)
                                                                                   364
       WRITE(6.7710) KKR
                                                                                   365
       WRITE(6.7707) (IBB(I).I=1.KKB)
•
                                                                                   366
           FD(1) = THE LOWER BOUND ON THE EXPECTED CRITICAL PATH TIME
                                                                                   367
 C
                   PLUS 1/IEDF OF THE DISTANCE TO THE UPPER BOUND
                                                                                   368
C
           NLFFD(I) = THE OBSERVED NUMBER OF CRITICAL PATH TIMES
                                                                                   369
 C
 C
                      THAT ARE < DR= FD(I)
                                                                                   370
          FD AND NLEFD ARE USED TO BUILD AN *EMPIRICAL * DISTRIBUTION OF
                                                                                   371
 C
                                                                                   372
 C
           THE CRITICAL PATH TIMES
                                                                                   373
C
                                                                                   374
       C=(CPU9-CPLB)/IEDF
                                                                                   375
       DO 6412 K=1,KCPB
       DO 6412 J=1.JEDF
                                                                                   376
                                                                                   377
       FD(I)=CPLB+I*C
                                                                                   378
       NLEFD(I) = 0
 6412
                                                                                   379
C
                                                                                   380
 C
          THE ASSOCIATE GROUPS ARE NOW FORMED
                                                                                   381
C
                                                                                   382
       WRITE(6,3165)
       FORMAT(1H1.5X."THE ASSOCIATES ARE NOW IDENTIFIED: 1)
                                                                                   383
 3165
                                                                                   384
       IIIIIIII
                                                                                   385
       Dn 2825 T=1.M
                                                                                   386
2825
       CTIME(I)=COT(I)
                                                                                   387
       I WWW Q= I CRITP(1)
                                                                                   388
       CHANG= LAMBDA+SIGMA(IWWWQ)
                                                                                   389
       TFX=COT(IWWWQ)-CHANG
                                                                                   390
       IF(TEX.LT.0.0) CHANG=COT(IWWWQ)
       CTIME(IWWWQ)=CDT(IWWWQ)-CHANG
                                                                                   391
                                                                                   392
       CALL BINVA($2800)
                                                                                   393
 2801
       CONTINUE
                                                                                   394
       IF(ISTAT(IWWWQ).FQ.1) CALL BINV1(822825,COT(IWWWQ).CTIME(IWWWQ).
                                                                                   395
      *IWWWO)
                                                                                   396
       REDCOS(IWWWQ) = REDCOS(IWWWQ)+COT(IWWWQ)-CTIME(IWWWQ)
                                                                                   397
 22825 CTIMF(IWWWQ)=COT(IWWWQ)
                                                                                   398
       IWWWQ=ICRITP(IIIII)
                                                                                   399
       CHANG= LAMBDA*SIGMA(IWWWQ)
                                                                                   400
       TEX=COT([WWWQ)-CHANG
                                                                                   401
       IF(TEX.LT.0.0) CHANG=COT(IWWWQ)
                                                                                   402
       CTIME([WWWQ)=CDT([WWWQ)-CHANG
       IF (ISTAT(IWWWQ).EQ.1) CALL BINY1(622800,CTIME(IWWWQ).COT(IWWWQ).
                                                                                   403
                                                                                   404
      *[WWWQ)
                                                                                   405
       REDCOS(IWWWQ)=REDCOS(IWWWQ)-COT(IWWWQ)+CTIME(IWWWQ)
                                                                                   406
       GO TO 22800
                                                                                   407
C
                                                                                   408
C
          DETERMINE ASSOCIATE GROUP
                                                                                   409
C
                                                                                   410
2910
       NINAG(IIIII)=0
                                                                                   411
       DO 2911 K=1.KKB
                                                                                   412
       KK=1
       IF (IBB(K).EQ.ICRITP(KK)) GO TO 2911
                                                                                   413
- 2913
       IF(KK.GE.KCPB) GO TO 2912
                                                                                   415
       KK=KK+1
                                                                                   416
       GO TO 2913
                                                                                   417
       NINAG(IIIII)#NINAG(IIIII)+1
2912
       ASSGRP(11111.NINAG(11111))=188(K)
                                                                                   415
```

2011

CONTINUE

```
86
        WRITE(6,2915) IIIII.ICRITP(IIIII).NINAG(IIIII)
                                                                                   420
 2915 FORMAT(1H0.10X. THE NUMBER OF ASSOCIATES ASSOCIATED WITH THE .. 13.
                                                                                   421
      **-TH CRITICAL PATH ACTIVITY, I.E. ACTIVITY **13.** IS = **13)
                                                                                   422
        IDUCK=NINAG(IIIII)
                                                                                   423
        IF(IDUCK.FG.0) GD TO 2810
                                                                                   424
        WRITE(6,2916) (ASSGRP(IIIII.I), I=1, IDUCK)
                                                                                   425
      FORMAT(1H0.15x, THE ACTIVITIES IN THE ASSOCIATE GROUP ARE AS FOLLO
                                                                                   426
      *WS*./.15X.57([3,*.*))
                                                                                   427
        11111=11111+1
                                                                                   428
        IF(IIIIII-LF-KCPB) GO TO 2801
                                                                                   429
 C
                                                                                   430
           DETERMINE THE CLUSTERS
 C
                                                                                   431
 C
                                                                                   432
 C
                THE CLUSTERS ARE POOLED TOWARD THE TERMINAL NODE
                                                                                   433
 C
                NCLUS = THE NUMBER OF NON-EMPTY CLUSTERS
                                                                                   434
                NINCL(I) = THE NUMBER OF ACTIVITIES IN THE I-TH CLUSTER
 C
                                                                                   435
 C.
                INCLUS([,J) = THE J-TH ACTIVITY IN THE I-TH CLUSTER
                                                                                   436
 C
                NCLINC(I) = THE NUMBER OF CLUSTERS COMPRISING THE I-TH
                                                                                   437
 C
                     CLUSTER AFTER POOLING
                                                                                   438
                CLINCL(I.J) = THE J-TH CLUSTER WHICH HAS BEEN POOLED INTO
 C
                                                                                   439
 C
                     THE I-TH CLUSTER
                                                                                   440
                                                                                   441
 C
 C
                NCLING AND CLINCL HELP KEEP TRACK OF WHICH CLUSTER THE
                                                                                   442
                CRITICAL PATH ACTIVITIES ARE IN
 C
                                                                                   443
 C
                                                                                   444
 C
                                                                                   445
          BFLOW FORMS CLUSTERS BY PUTTING FACH CRITICAL PATH ACTIVITY IN
 c
                                                                                   446
          SEPARATE CLUSTER AND THEN ADDING EACH CRITICAL PATH ACTIVITY'S
 C
                                                                                   447
 C.
          ASSOCIATES TO ITS CLUSTER
                                                                                   448
                                                                                   449
 C
                                                                                   450
       NCLUS=KCPR
       DO 3r20 I=1.KCPB
                                                                                   451
                                          COPY AVAILABLE TO DDC DOES NOT
                                                                                   452
       NCL INC(I)=1
                                                                                   453
       CLINCL(I.1)=I
                                          PERMIT_FULLY_LEGIBLE_PRODUCTION
                                                                                   454
       NINC(I) = NINAG(I)+1
       INCLUS([,1)=ICRTTP(I)
                                                                                   455
       IF(NINAG(I).EQ.0) GO TO 3020
                                                                                   456
       IDUCK=NINCL(I)
                                                                                   457
                                                                                   458
       DO 3021 J=2. IDUCK
                                                                                   459
       1-L=LL
 3021
       INCLUS(I.J)=ASSGRP(I.JJ)
                                                                                   460
                                                                                  461
 3020
       CONTINUE
                                                                                   462
. (
          BELOW POOLS CLUSTERS FORMED FROM ASSOCIATES
                                                                                   463
 С
 C
                                                                                  464
                                                                                   465
       IA=C
                                                                                  466
 3031
       IA=IA+1
       IF(IA.GE.KCPB) GO TO 3030
                                                                                  467
       IF(NCLUS.EQ.1) GD TO 3030
                                                                                  468
                                                                                  469
       IDIA=NINCL(TA)
                                                                                  470
       IF(101A.FQ.0) GO TO 3031
                                                                                  471
       TAA=TA+1
       DO 3023 IT=IAA.KCPB
                                                                                   472
                                                                                  473
       IDII=NINCL(II)
       IF (IDII.EQ.0) GO TO 3023
                                                                                  474
                                                                                  475
       DU 3025 1=1.1D[4
                                                                                  476
       00 3025 J=1.1011
       IF (INCLUS(II.J).FQ. INCLUS([A.I)) GO TO 3027
                                                                                  477
                                                                                  478
       CONTINUE
 3025
```

GO TO 3023

```
3027
      NCLUS=NCLUS-1
                                                                                  480
                                                                                  481
      DO 3028 J=1.IDII
      DO 3029 1=1.IDIA
                                                                                  482
       IF(INCLUS(II.J).FQ. INCLUS(IA.I)) GO TO 3028
                                                                                  483
3029
                                                                                  484
                                                                                  485
       NINCL(IA)=NINCL(IA)+1
       INCLUS(IA, NINCL(IA) )=INCLUS(II.J)
                                                                                  486
                                                                                  487
3028
      CONTINUE
                                     COPY AVAILABLE TO DDG DOES NOT
      NINCL(II)=0
                                                                                  488
      NCL INC(IA)=NCLINC(IA)+1
                                                                                  489
                                     PERMIT FULLY LEGIBLE PRODUCTION
      CLINCL(IA.NCLINC(IA)) = II
                                                                                  490
                                                                                  491
      NCLINC(II)=7
                                                                                  492
3023
      CONTINUE
      GO TO 3031
                                                                                  493
                                                                                  494
3030
      CONTINUE
                                                                                  495
C
          BELOW DESCRIBES CLUSTERS AFTER POOLING BASED ON THE ASSOCIATES
                                                                                  496
                                                                                  497
                                                                                  498
      WRITE(6.3033) NCLUS
     FORMAT (1H1,10X, THERE ARE 1,13.1 NONEMPTY CLUSTERS AFTER POOLING O
                                                                                  499
3033
                                                                                  500
     *N THE RASIS OF ASSOCIATES ONLY. 1)
                                                                                  501
      TITE
      DO 3034 I=1.KCPB
                                                                                  502
      IF(NINCL(I).E0.0) GD TO 3034
                                                                                  503
                                                                                  504
      II=II+1
      IDUCJ=NINCL(I)
                                                                                  505
                                                                                  506
      WRITF(6.3035) I.(INCLUS(I.J).J=1.IDUCJ)
      FORMAT (1HO . 10X . THE ACTIVITIES IN THE . 13. -TH CLUSTER ARE AS FOL
                                                                                  507
3035
                                                                                  508
     *LOWS:++/+15X+50([3+'+'))
                                                                                  509
3034
      CONTINUE
                                                                                  510
C
         DESCRIBES WHERE EACH ACTIVITY IS BEFORE ELIMINANTS ARE
                                                                                  511
C
                                                                                  512
C
         CONSIDERED
                                                                                  513
                                                                                  514
•
         EXAMINE EACH ACTIVITY AND DETERMINE WHICH CLUSTER-IF ANY. IT IS
                                                                                  515
C
                                                                                  516
C
                             IMPLIES THAT THE I-TH ACTIVITY IS NOT IN ANY
                                                                                  517
C
               LFFT(1) = 0
                                                                                  518
                             CLUSTER
C
                            IMPLIES THE I-TH ACTIVITY IS IN THE J-TH
                                                                                  519
C
               LEFT(1) = J
                            CLUSTER
                                                                                  520
C
                                                                                  521
                                                                                  522
      WRITE(6,3104)
      FORMAT (1HO.10X. THE CLUSTER TO WHICH FACH ACTIVITY BELONGS: . /. 15X
                                                                                  523
3104
     **(ZFRO IMPLIES THAT THE ACTIVITY IS NOT IN ANY CLUSTER)*)
                                                                                 5 24
                                                                                  525
      DO 3101 T=1.M
                                                                                  526
      LFFT(I)=C
                                                                                 527
      DO 3102 J=1,KCP8
                                                                                 528
      IF(NINCL(J).FQ.0) GO TO 3102
                                                                                  529
      IDUCK=NINCL(J)
                                                                                  530
      DO 3110 K=1, IDUCK
      IF(I.EQ.INCLUS(J.K)) GD TO 3107
                                                                                  531
                                                                                  532
      CONTINUE
3110
                                                                                 533
3102
      CONTINUE
                                                                                  534
      60 TO 3101
                                                                                 535
      LEFT(1)=J
31C7
      WRITE(6,3103) I,LEFT(1)
                                                                                 536
3101
     FORMAT (1H +15x++THE ++13++-TH ACTIVITY IS IN THE ++13.4-TH CLUSTER
                                                                                 537
3103
                                                                                  538
     * * )
```

INDEXL = 1

```
88
                                                                                  540
C.
          LEFTOVERS ARE ACTIVITIES NOT IN CLUSTERS AFTER ASSOCIATES HAVE
                                                                                  541
          9FEN CONSIDERED BUT BEFORE FLIMINANTS HAVE BEEN CONSIDERED
                                                                                  542
C
                                                                                  543
C
                                                                                  544
C
          DETERMINE THE NUMBER OF LEFTOVERS. NLFFT
                                                                                  545
^
                              IMPLIES THAT THE L-TH LEFTOVER IS THE J-TH
               LFFTO(L) = J
                                                                                  546
•
                              ACTIVITY
                                                                                  547
                                                                                  548
      NI FFT= ?
                                                                                  549
      90 3122 J=1.M
                                                                                  550
      IF(LEFT(J).NE.0) GO TO 3122
                                                                                  551
      NLFFT=NLEFT+1
                                                                                  552
      LFFTO(NLEFT)=J
                                                                                  553
3122
      CONTINUE
                                                                                  554
      WRITE(6.3123) NLFFT
                                                                                  555
      FORMAT (1H0,10X, THERE AFE 1,13, ACTIVITIES NOT IN ANY CLUSTER YE
3123
                                                                                  556
                                                                                  557
      WRITE(6.3323)
                                                                                  558
3323
      FORMAT (1H1.5X.+THE FLIMINANTS OF FACH NON-CRITICAL-PATH ACTIVITY A
                                                                                  559
     *RE NOW DETERMINED: 1)
                                                                                  560
                                                                                  561
ς.
C
         FLIMINANTS FOR EACH NON-CRITICAL-PATH ACTIVITY ARE NOW
                                                                                  562
C
         DETERMINED
                                                                                  563
               NNNCP = THE NUMBER OF ACTIVITIES NOT ON THE CRITICAL PATH
C
                                                                                  564
C
               NONCP(LE) - THE LE-TH ACTIVITY NOT ON THE CRITICAL PATH
                                                                                  565
                                                                                  566
C
      NNNCF=M-KCP3
                                                                                  567
      LE=r
                                                                                  568
      DO 5000 T=1.M
                                                                                  569
                                                                                  57C
                                       COPY AVAILABLE TO DDG DOES NOT
      IF(I.EQ.ICRITP(J)) GO TO 5000
                                                                                  571
                                                                                  572
                                       PERMIT FULLY LEGIBLE PRODUCTION
      IF(J.LF.KCPA) GO TO 5001
                                                                                  573
5002
      LF=LF+1
                                                                                  574
                                                                                  575
      NUNCP(LF) = I
5000
      CONTINUE
                                                                                  576
      WRITE(6,5005) NNCP
                                                                                  577
     FORMAT(1H0.05%, THERE ARE 1.13.1 ACTIVITIES NOT ON THE CRITICAL PA
                                                                                  578
5005
                                                                                 579
           THEY ARE AS FULLOWS: 1)
      IF(NNCP-E9-0) GO TO 3124
                                                                                  580
      DO 5006 T=1.LE
                                                                                 581
                                                                                 582
5005
      WPITE(6.5007) I.NUNCP(I)
                                                                                 583
5007
      FORMAT (1H +15X+13+'+
      TF(NNNCP.FQ.C) GD TD 3124
                                                                                 584
      LF=C
                                                                                 585
3126 LE=LF+1
                                                                                 586
      IF (ISTAT(IWWWQ).ED.1) CALL RINVI(623127.COT(IWWWQ).CTIME(IWWWQ).
                                                                                 587
                                                                                 588
      REDOOS (IWWWO) = PEDOOS(IWWWQ)-CTIME(IWWWQ)+COT(IWWWQ)
                                                                                 589
                                                                                 590
23127 CONTINUE
      CTIMF(IWWWQ) = COT(IWWWQ)
                                                                                 591
      CTIME(NONCP(LE)) = COT(NONCP(LE)) + THETA*SIGMA(NONCP(LE))
                                                                                 592
      THE (ISTATINGNOP(LE)).EQ.1) CALL HINV1(E7756.CTIME(NONOP(LE)).
                                                                                 593
         COT (NUNCO(LE)). NONCO(LE))
                                                                                 594
      PEDCOS (NONCP(LE)) #PFDCOS (NONCP(LE)) + COT (NONCP(LE)) + CT IME (NONCP(LE)
                                                                                 595
                                                                                 596
     *)
                                                                                 597
 7756 IWWWG = NONCP(LE)
      WRITE(6.3152) NONCP(LE)+CTIME(NONCP(LF))
                                                                                 598
```

FORMAT(1HG.///, 5x.+THE COMPLETION TIME FOR THE \*.13.4-TH ACTIVITY

3152

599

```
* HAS BEEN CHANGED TO .E15.5)
                                                                                    600
        CORSS OF OD
                                                                                    601
 3121
       CONTINUE
                                                                                    602
 C
                                                                                    603
 C
           DETERMINE THE ELIMINANTS OF THE LE-TH ACTIVITY NOT ON THE
                                                                                    604
 C
           CRITICAL PATH
                                                                                    605
 C
                           = THE NUMBER OF ELIMINANTS FOR THE LE-TH
                                                                                    606
 C
                             ACTIVITY NOT ON THE CRITICAL PATH
                                                                                    607
 \mathbf{c}
                FGRP(J)
                              = THE J-TH ELIMINANT FOR THE LE-TH ACTIVITY
                                                                                    608
 C
                                NOT ON THE CRITICAL PATH
                                                                                    609
 C
                                                                                    610
                                                                                    611
       NE =C
                                                                                    612
       DO 3130 K=1.KCPB
       DO 3131 T=1,KKB
                                                                                    613
                                                                                    614
        IF ( TBB ( I ) . EQ . ICRITP (K) ) GO TO 3130
                                                                                    615
 3131
       CONTINUE
       NE=NE+1
                                                                                    616
                                                                                    617
       EGRP(NE)=ICRITP(K)
 3130
       CONTINUE
                                                                                    618
                                                                                    619
       WRITE(6,3133) NE,NUNCP(LE)
 3133 FORMAT (1HO+10X+*THERE ARE *+13+* ELIMINANTS CORRESPONDING TO ACTIV
                                                                                    620
      *ITY *, [3)
                                                                                    621
                                                                                    622
       TF(NE+EQ+0) GO TO 3171
                                                                                    623
       DO 3135 K=1.NE
 3135
       WRITE(6,3136) K, NONCP(LE), FGRP(K)
                                                                                    624
* 3136 FORMAT(!H +14x++THF ++13.+-TH ELIMINANT CORRESPONDING TO ACTIVITY
                                                                                    625
      **,13.* IS ACTIVITY *,13)
                                                                                    626
                                                                                    627
 C
          DETERMINE WHETHER NONCP(LE) IS AN ASSOCIATE
                                                                                    628
٠ ر
                       IF NONCP(LE)
                                      IS AN ASSOCIATE
                                                                                    629
 C
                I = AL
                         IF NONCP(LE)
                                        IS NOT AN ASSOCIATE
                                                                                    630
 C
                                                                                    631
 C
       K=NONCP(LE)
                                                                                    532
                                                                                    633
       JA=1
       IF(LEFT(K).EQ.O) JA=2
                                                                                    634
                                                                                    635
       IF(JA.EQ.2) GO TO 5010
                                                                                    636
       T=LEFT(K)
                                                                                    637
          THE IT-TH CLUSTER IS EXPANDED TO INCLUDE ELIMINANTS
 C
                                                                                    638
· С
                                                                                    639
       GO TO 5011
                                                                                    640
 5010
                                                                                    641
       CONTINUE
                                                                                    642
. C
          ITTYT IS THE ACTIVITY NUMBER OF THE FIRST FLIMINANT
 C
                                                                                    643
          IT IS THE CLUSTER TO WHICH THE FIRST ELIMINANT CURRENTLY BELONG
 C
                                                                                    644
                                                                                    645
 C
       ITTT=EGFP(1)
                                                                                    646
                                                                                    647
       IT=LFFT(ITTT)
                                                                                   648
       LEFT(NONCP(LF))=IT
                                                                                    649
 C
                                                                                   650
          THE IT-TH CLUSTER IS EXPANDED TO INCLUDE ELIMINANTS
 C
                                                                                   651
 C
                                                                                   652
       NINCL(IT)=NINCL(IT)+1
                                                                                   653
       INCLUS(IT, NINCL(IT))=NONCP(LE)
                                                                                   654
       IF(NF.EG.1) GO TO 3171
                                                                                    655
       DO 3172 J=JA.NE
 5011
                                                                                   656
. C
                                                                                   657
          IU IS THE ACTIVITY NUMBER OF THE NEXT ELIMINANT
 C
          IF IU IS IN CLUSTER K. THEN CLUSTER K IS POOLED INTO CLUSTER IT
 C
                                                                                   658
```

C

```
IU=EGRP(J)
                                                                                 660
      K=LEFT(IU)
                                                                                 661
      IF(IT.EQ.K) GO TO 3172
                                                                                 662
3182
                                                                                 663
      NCLUS=NCLUS-1
      IW=NCLINC(K)
                                                                                 664
      DO 3183 IA=1.IW
                                                                                 665
      LEFT(ICRITP(CLINCL(K.IA)))=IT
                                                                                 666
      NCLINC(IT)=NCLINC(IT)+1
                                                                                 667
3183
      CLINCL(IT.NCLINC(IT)) = CLINCL(K.IA)
                                                                                 668
      NCLINC(K)=0
                                                                                 669
      IW=NINCL(K)
                                                                                 670
                                                                                 671
      NINCL(K)=0
      DO 3184 IA=1.IW
                                                                                 672
                                                                                 673
      LEFT(INCLUS(K, IA))=IT
                                                                                 674
      NINCL(IT)=NINCL(IT)+1
                                                                                 675
3184
      INCLUS(IT, NINCL(IT))=INCLUS(K.IA)
                                                                                 676
3172
      CONTINUE
                                                                                 677
3171
      CONTINUE
      IF (LE.LT.NNNCP) GO TO 3126
                                                                                 678
                                                                                 679
C
         END OF POOLING BASED ON FLIMINANTS EXCEPT FOR THE FOLLOWING
                                                                                 680
С
                                                                                 681
C
         DESCRIPTION
                                                                                 682
C
      WRITE(6.3173) NCLUS
                                                                                 683
3173
      FORMAT (1H1,25X, 'THERE ARE '. 13, ' CLUSTERS.')
                                                                                 684
                                                                                 685
      DO 3176 T=1.KCPB
      IF(NINCL(I).EQ.0) GO TO 3176
                                                                                 686
                                                                                 687
      IDD=NINCL(I)
                                                                                 688
      WRITE(6.3174) NINCL(1), 1, (INCLUS(1, J), J=1, IDD)
                                                                                 689
3174
      FORMAT (1H0,10X, THERE ARE 1,13, ACTIVITIES IN THE 1,13, THE CLUST
           THEY ARE AS FULLOWS: 1./.20x.50(13.1.1)
                                                                                 690
     *EP.
      IDUCK=NCLINC(I)
                                                                                 691
      WRITE(5.3175) NCLINC(I).(CLINCL(I.J).J=1.IDUCK)
                                                                                 692
3175 FORMAT (1H0.15x,13. CLUSTERS HAVE BEEN POOLED TO MAKE THIS CLUSTER
                                                                                 693
     *. THEY WERE AS FOLL(WS: 1./.20X.50([3.1.1))
                                                                                 694
                                                                                 695
3176 CONTINUE
      WPITE (6,2776) SAMSIZ
                                                                                 696
                                                                                 697
 2776 FORMAT (///5X+
                              . THE NUMBER OF PERCENTILE COMBINATIONS EXP
     *LIGITLY CONSIDERED IN DETERMINING THE UPPER BOUNDS AND LOWER BOUND
                                                                                 698
                                                                                 699
     *S*/,6X,*ON THE NETWORK COMPLETION TIME DISTRIBUTION AND THE UPPER
                                                                                 700
     *ROUNDS ON ITS MOMENTS IS FQUAL TO 1,15)
                                                                                 701
      CALL CLOCK (XRAN)
                                                                                 702
      IYUTS = XPAN
                                                                                 703
      WRITE (6.3238) IYUTS
 3238 FORMAT (1H0.5X. THE INITIALIZATION PAPAMETER FOR THE SAMPLING IS I
                                                                                 704
                                                                                 705
     *Y = *, *I1C)
                                                                                 706
C
         STATEMENT NUMBER 3124 MARKS THE END OF POOLING CLUSTERS BASED
                                                                                 707
C
                                                                                 708
              ON LEFTOVERS AND ELIMINANTS
C.
                                                                                 709
C
                                                                                 710
3124 CENTINUE
                                                                                 711
C
                                                                                 712
C
         THE FINAL CLUSTERS HAVE NOW BEEN DETERMINED
                                                                                 713
C
                                                                                 714
         THE 2**NINCL(I) RUNS ARE NOW AVERAGED FOR ALL I WITH NINCL(I)>0
C
         THE 122( ) ARE USED TO REPRESENT ALL OF THE 2**NINCL
                                                                                 715
C
                                                                                 716
         POSSIBILITIES.
C
                                                                                 717
         THIS IS WHERE THE BINARY REPRESENTATION IS CONSTRUCTED.
C
                                                                                 718
C
```

6008

IF(ICBCP.EO.1) ICBCP=2

```
91
        INDEXL=2
                                                                                      720
        18=0
                                                                                     721
 3200
                                                                                     722
        IR=IR+1
        DO 6031 I=1,10
                                                                                     723
 60 31
        MOMENT(IR \cdot I) = 0.0
                                                                                     724
        IF(IR.GT.KCP8) GO TO 3208
                                                                                     725
        IF(NINCL(IR).EQ.0) GO TO 3200
                                                                                     726
                                                                                     727
        IDUCK=NCLINC(IR)
        DO 3410 1=1.1DUCK
                                                                                     728
        K=CLINCL(IR.I)
                                                                                     729
                                                                                     730
 3410
       CONTINUE
       L=ICRITP(K)
                                                                                     731
 3310
       IP = C
                                                                                     732
                                                                                     733
        NIR= C
                                                                                     734
 C
 C
              = NUMBER OF PERCENTILE COMBINATIONS IN THE SAMPLE
        NIR
                                                                                     735
        PNIB = PERCENTAGE OF THE TOTAL NUMBER OF PERCENTILE COMBINATIONS
                                                                                     736
 C
                EXPLICITLY CONSIDERED
                                                                                     737
        NSAVE = VECTOR CONTAINING THE LOWER BOUNDS ON THE NETWORK
                                                                                     738
 C
 C
                COMPLETION TIME DISTRIBUTION TO BE AVERAGED WITH THE
                                                                                     739
 C
                UPPER BOUNDS ON THE NETWORK TO YIELD THE AVERAGE NETWORK
                                                                                     740
 C
                COMPLETION TIME DISTRIBUTION.
                                                                                     741
 C
                                                                                     742
        KNIR = NIR ASSOCIATED WITH NSAVE.
                                                                                     743
 C
 C
                                                                                     744
                                                                                     745
        IC=NINCL(IR)
                                                                                     746
        IB=2**NINCL(IR)
        IDDALL = 1 MEANS ALL PERCENTILE COMBINATIONS ARE EXPLICITLY
                                                                                     747
 c
                                                                                     748
 C
                 CONSIDERED.
 c
        IDDALL = 0 MEANS TO SAMPLE.
                                                                                     749
                                                                                     750
 C
                                                                                     751
       IDCALL = 0
                                                                                     752
       IF (SAMSIZ.LE.O.OP.SAMSIZ.GE.IB) IDOALL=1
                                                                                     753
       DC 3222 I=1.M
                                                                                     754
                                                                                     755
  3222 \text{ CTIME(I)} = \text{COT(I)}
                                                                                     756
       C0000 DT DD
 C
                                                                                     757
           STATEMENT 3204 IS THE RE-ENTRY POINT FROM THE DUAL SIMPLEX
                                                                                     758
 C
           ALGORITHM WHEN A CLUSTER AVERAGE IS BEING COMPUTED
                                                                                     759
. c
 C
                                                                                     760
                                                                                     761
 3204
       CONTINUE
                                                                                     762
       IF (IDLB.EG.1) GO TO 9900
                                                                                     763
       DO 6032 I=1.10
                                                                                     764
       MOMENT([R.]) = MCMENT([R.]) + B1[NV(1.NMMP1)**[
 6032
       IF (ICBCP.NE.2) GO TO 10001
                                                                                     765
                                                                                     766
 9900
       X= BITNV(1.NMMP1)
                                                                                     767
       X=X-1.0D-10
                                                                                     768
       1=0
                                                                                     769
 6420
       I = I + 1
                                                                                     770
       IF(x.GT.FD(I)) GO TO 6420
                                                                                     771
       NLEFD(I) = NLEFD(I) + 1
                                                                                     772
 10001 CONTINUE
                                                                                     773
. 2000C IP=IP+1
                                                                                     774
       NIB = NIB+1
                                                                                     775
C
          GENERATE NEXT PERCENTILE COMBINATIONS TO BE EXPLICITLY
                                                                                     776
- C
                                                                                     777
          CONSIDERED.
C
                                                                                     778
```

IF (IDUALL.EQ.C) GO TO 20500

781

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793 794

795 796

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808 809

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814

815

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819 820

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823

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825

826

827

828

829

830

631

A32

633

834

A35

8 36

A37

6.38

839

```
IF (IP.GT.IB) GD TO 3207
      RANSAM = IP
      GO TO 20501
20500 IF (NIB.GT.SAMSIZ) GO TO 3207
      IYUTS = IYUTS *65539
      IF (IYUTS) 6210,6211,6211
 6210 IYUTS = IYUTS+2147483647+1
 6211 XRAN = IYUTS
      XRAN = XRAN + .4656613F-9
      RANSAM = XRAN*DFLDAT(IB-1) + 1
20501 CONTINUE
C
      CONVERT THE RANDOM NUMBER, RANSAM, TO A BINARY NUMBER TO DEFINE A
C
C
      PERCENTILE COMBINATION.
      KRAN = FANSAM
      DC 8505 I=1.1C
      IHALF = KRAN/2
      IZ = KRAN - IHALF*2
      L = INCLUS([P.1)
      CTIME(L) = IZ*FHI(L)-IZ*FLO(L) + FLO(L)
      KRAN = IHALF
8505
      CALL BINVA(82800)
      NIR = NIB-1
3207
      IF (IDL8.FQ.1) GO TO 9011
      DO 6030 I=1.10
      MOMENT(IR.I) = MOMENT(IR.I)/NIB
6030
      IF (ICBCP.E2.2) GO TO 6011
      GO TO 3200
      WRITE (6.6362)
3208
      FORMAT (1H1)
6362
      PNTB = DFLOAT(NIB*100)/DFLOAT(IB)
      IF (SAMS17.LF.0) WRITE(6,6045)
      IF (SAMSIZ.GT.C) WRITE(6.6056) SAMSIZ
 6056 FORMAT ( 5x. THE FOLLOWING TABLE WAS COMPUTED CONSIDERING AT MOST
     *'. IA.' FERCENTILE COMBINATIONS .')
 6046 FORMAT( 5x. THE FOLLOWING TABLE WAS COMPUTED CONSIDERING ONLY 1.
       18. PERCENTILE COMBINATIONS OR ...F6.2. PERCENT OF ALL COMBINA
     *TICNS. 1)
 6C45 FORMAT (5X. THE FOLLOWING TABLE WAS COMPUTED CONSIDERING ALL PERC
     *ENTILE COMBINATIONS.*)
      DO 10000 J=1.10
      C=XAMT1
      TMAX=0 .
      DO 5021 T=1,KCP9
      IF(NINCL(I).FQ.0) GO TO 5021
      IF (MOMENT(I.J).LE.TMAX) GO TO 5021
      TMAX = MCMENT(I,J)
      I TMAX= [
      CONTINUE
5021
      WRITE (6.5023) J.J.MOMENT(ITMAX.J)
      FORMAT (1H0.5X. A LOWER BOUND. T-(1.12. THETA. LAMBDA). ON THE !
5023
              12 .-- TH MOMENT OF THE NETWORK COMPLETION TIME = 1.615.5)
10000
       CONTINUE
C
         BEGIN THE PROCEDURE FOR DETERMINING UPPER BOUNDS ON THE MOMENTS
C
         OF THE NETWORK COMPLETION TIME AND LOWER BOUNDS ON THE
C
         DISTRIBUTION OF THE COMPLETION TIMES.
C
```

C

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93
```

```
C
           POOL ALL OF THE PREVIOUS CLUSTERS INTO ONE CLUSTER
                                                                                     840
 C
           NCL = THE INDEX OF THE RESULTANT POOLED CLUSTER
                                                                                     841
           NNCL = THE NUMBER OF ACTIVITIES IN THIS POOLED CLUSTER
                                                                                     842
 C
                                                                                     843
 C
       IF(NCLUS.GT.1) GO TO 5000
                                                                                     844
                                                                                     845
       I = 0
                                                                                     846
 5001
       I = I + 1
       IF(NINCL(I).EQ.0) GD TO 6001
                                                                                     847
                                                                                     848
       NCL=I
       GO TO 6002
                                                                                     849
                                                                                     850
 5000
       NMAX = 0
       DO 6003 I=1.KCPB
                                                                                     851
                                                                                     852
       IF(NINCL(I) . LE . NMAX) GO TO 6003
                                                                                     853
       NCI = T
                                                                                     854
       NMAX=NINCL(I)
                                                                                     855
       CONTINUE
 6003
                                                                                     856
       DO 6004 I=1.KCPB
       IF(NINCL(I).EQ.0) GD TO 6004
                                                                                     857
                                                                                     858
       IF(I.FG.NCL) GO TO 6004
                                                                                     859
       K=NINCL (NCL)
                                                                                     860
       JJ=NINCL(I)
                                                                                     861
       NINCL(I)=0
       DO 6005 J=1.JJ
                                                                                     862
                                                                                     863
       K=K+1
                                                                                     864
 60.05
       INCLUS(NCL,K)=INCLUS(1.J)
                                                                                     865
       NINCL(NCL)=NINCL(NCL)+JJ
                                                                                     866
 6004
       CONTINUE
                                                                                     867
 6002
       NNCL=NINCL(NCL)
                                                                                     868
 C
 C
                                                                                     869
                                                                                     870
 C
          THE UPPER BOUNDS: T+(R:THETA:LAMBDA): ARE NOW DETERMINED:
                                                                                    871
 C
                                                                                    872
 C
                                                                                     873
 C
          FOR THE SAKE OF NUMERICAL ACCURACY THE PERT PROBLEM
                                                                                     874
 C
          WITH NEW ACTIVITY TIMES IS INITIALLY SOLVED FROM SCRATCH
                                                                                     875
 C
                                                    AFTER THIS
                                                                                    876
           INSTEAD OF UPCATING AN OLD SOLUTION.
 C
                                                                                     877
          REINITIALIZATION. THE PEMAINING CRITICAL PATH TIMES ARE
 C
C
          DETERMINED BY UPDATING THIS SOLUTION.
                                                                                    878
                                                                                     879
                                                                                     880
       DD 6006 I=1.N
                                                                                    881
       CTIME( I )=FHI( I )
                                                                                     882
       COT(I)=FHI(I)
6006
                                                                                    883
       DO 6007 J=1.NNCL
                                                                                     884
       I = INCLUS(NCL.J)
                                                                                    885
 6007
       CTIME([)=.5*(FLO([ )+FHI([ ))
                                                                                    886
       DO 7101 I=1. IEDF
                                                                                    887
       NLEFD(I) = 0
 7101
                                                                                    888
       ICACP=1
                                                                                    887
       GO TO 6010
                                                                                     890
       WRITE (6,6264)
 6011
                                                                                    891
       FORMAT(///)
 6264
                                                                                     892
       PNIB = DFLOAT(NIB*100)/DFLOAT(IB)
                                                                                    893
       IF (IDOALL.EQ.O) WRITE(6.6046) NIB.PNIB
                                                                                    894
       IF (IDOALL.EG.1) WRITE(6.6045)
                                                                                    895
       DO 10009 J=1.10
                                                                                    896
. 10009 WRITE (6.6012) J.J. MOMENT(NCL.J)
       FORMAT (1H0.5%. AN UPPER BOUND. T+(+,12.4;THETA.LAMBDA). ON THE *
                                                                                     897
 6012
      *.12. -- TH MOMENT OF THE NETWORK COMPLETION TIME = *.E15.5)
                                                                                    978
                                                                                    899
       DO 6900 1=2.1EDF
```

```
94
        II = I - 1
 6900
       NLEFD(I) = NLEFD(I) + NLEFD(II)
        WPITE (6.6362)
       PNIB = DFLOAT(NIB*100)/DFLOAT(IB)
        IF (IDOALL.EG.O) WRITE(6.6046) NIB.PNIB
        IF (IDOALL.EG.1) WRITE(6,6045)
       WPITE(6,6423)
       FORMAT(1HC.5x. 'A LOWER BOUND ON THE NETWORK COMPLETION TIME DISTR
 6423
      *IBUTION: F-(.; THETA; LAMBDA) )
       KNIB = NIB
       DO 6421 I=1. IEDF
       NSAVE(I)=NLEFD(I)
       X=NLEFO(1)
       X=X/N13
 6421
       WRITE(6,6422) FD(1), THETA, LAMBDA, X
       FORMAT(17x, *F-(*,E15.5, *; *,E15.5, *; *,E15.5, *) = *,E15.5)
 6422
 C
 C
 C
          BEGIN THE PROCEDURE FOR DETERMINING UPPER BOUNDS ON THE
 C
          NETWORK COMPLETION TIME DISTPIBUTION
 C
 C
          FOR THE SAKE OF NUMERICAL ACCURACY THE PERT PROBLEM
 C
          WITH NEW ACTIVITY TIMES IS INITIALLY SOLVED FROM SCRATCH
 C
          INSTEAD OF UPDATING AN OLD SOLUTION.
                                                 AFTER THIS
 C
          RETNITIALIZATION, THE REMAINING CRITICAL PATH TIMES ARE
 C
          DETERMINED BY UPDATING THIS SOLUTION.
       DO 9006, I=1.M
       CTIME([)=FLO([)
       COT(I)=FLO(I)
- 9006
       DO 9007 J=1.NNCL
       I = INCLUS (NCL.J)
 9007
       CTIME(1)=+5*(FLO(1 )+FHI(I ))
       DO 9101 I=1.IFDF
       NLFFD(I) = 0
 9101
       ICBCP = 1
       IDLB = 1
       GO TO 6010
       DO 9990 1=2.1EDF
 9011
       11=1-1
       NLEFD(I) = NLEFD(I) + NLEFD(II)
- 9990
       WRITE (6.6254)
       PNIB = DFLOAT(NIB*100)/DFLOAT(IB)
       IF (IDDALL .EQ.0) WRITE(6,6(46) NIB,PNIB
       IF (IDDALL.FQ.1) WRITE(6.6045)
       WRITE(6,9423)
 9423 FORMAT(1H0,5X, AN UPPER BOUND ON THE NETWORK COMPLETION TIME DISTR
      *IBUTION: F+(+;THFTA;LAMBDA)+)
       DO 9421 I=1.IEDF
       X=NLEFO(1)
       PIN\X=X
 9421
       WPITF(6,9422) FD(1), THETA, LAMBDA, X
       FORMAT(17X,*F+(*,E15.5,*;*,E15.5,*;*,F15.5,*) = *,E15.5)
 9422
 C
          THE APPROXIMATE NETWORK COMPLETION TIME DISTRIBUTION
. C
       WRITE (6.6362)
 C
       WRITE(6.9472)
       FORMAT(1H0.5X. AN APPROXIMATE NETWORK COMPLETION TIME DISTRIBUTION
 9472
```

\*:'.//.15x.'F(.:THETA.LAMBDA) = .5 + ( F+(.:THETA.LAMBDA) + FF-(.:TH

\*ETA.LAMBDA) ) ..//)

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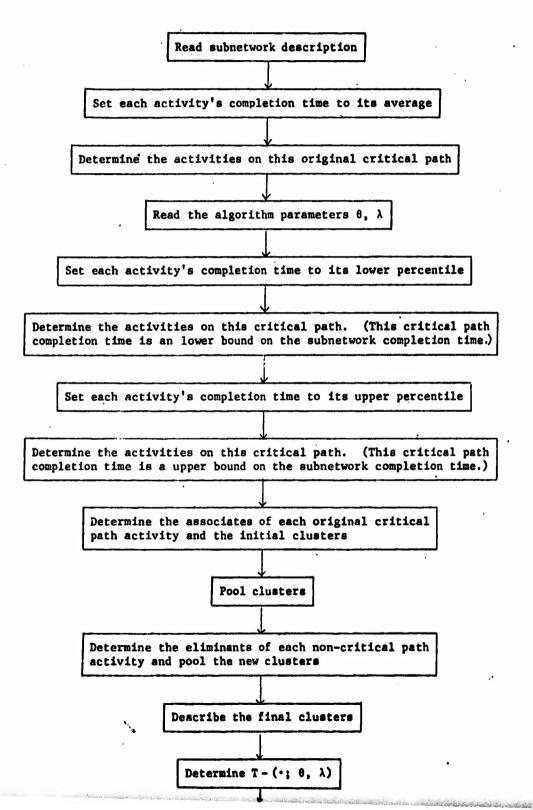
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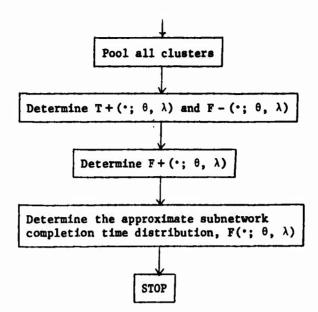
959

```
DO 9471 I=1. IEDF
                                                                                   960
                                                                                   961
       X = .5*DFLOAT(NSAVE(I))/KNIB+.5*DFLOAT(NLEFD(I))/NIB
9471
       WRITE(6.9473) FD(1).THETA.LAMBDA.X
                                                                                   962
9473
                                                                                   963
       FORMAT(17X, F(*,E15.5,*;*,E15.5,*;*,E15.5,*) = *,E15.5)
999
                                                                                   964
       WRITE(6.850)
                                                                                   965
       STOP
       END
                                                                                   966
       SUBROUTINE BINVA(*)
                                                                                   967
                                                                                   968
       IMPLICIT REAL+8 (A-H+D-Z)
                                                                                   969
       COMMON BIINV, REDCOS, CTIME, XRI. INBASE, IHEAD, ITAIL, NMMP1, NMM, N. ISTAT
                                                                                   970
       COMMON M.MP1
       DIMENSION ISTAT(100). IHEAD(60). ITAIL(60). XB1(41)
                                                                                   971
                                                                                   972
       DIMENSION 311NV(41.41). INBASE(40).CTIME(100).REDCOS(100)
                                                                                   973
C
C
                                                                                   974
          UPDATE THE FIRST ROW OF BIINV AFTER CHANGING CTIME
                                                                                   975
C
                                                                                   976
       DO 1 1=2.NMMP1
                                                                                   977
       B1INV(1.I) = 0.0
                                                                                   978
       DO 1 J=2. NMMP1
     1 BIINV(1.1) = BIINV(1.1) + BIINV(J.1)*CTIME(INBASE(J-1))
                                                                                   779
                                                                                   980
                                                                                   981
C
          UPDATE VALUE OF THE OBJECTIVE FUNCTION
                                                                                   982
                                                                                   983
       XB1(1) = B1INV(1,NMMP1)
       RETURN1
                                                                                   984
                                                                                   985
       FND
                                                                                   986
       SUBROUTINE BINVI (*. TMNEW. TMOLD. ID)
                                                                                   987
       IMPLICIT REAL+8 (A-H+0-Z)
                                                                                   988
       COMMON BIINV, REDCOS, CTIME, XB1. INBASE. IHEAD. ITAIL. NMMPI. NMM. N. ISTAT
                                                                                   989
       COMMON M.MPI
       DIMENSION
                                                                                   990
                 ISTAT (100), IHEAD(60), ITAIL(60) . XB1(41)
       DIMENSION BIINV(41.41), INBASE(40), CTIME(100), REDCOS(100)
                                                                                   991
                                                                                   992
C
          COMPUTE THE REDCOS CORRESPONDING TO ONE CHANGE IN CTIME
                                                                                   993
C
                                                                                   994
                                                                                   995
       DO 2 I=1.NMM
                                                                                   996
     2 IF(INRASE(I).EQ.ID) II=I+1
                                                                                   997
       DIFF = TMNEW-TMOLD
                                                                                   998
C
          THINEW IS THE NEW TIME AND THOLD IS THE OLD TIME CORRESPONDING
                                                                                   999
          TO THE SINGLE CHANGE IN CTIME
C
                                                                                  1000
C
                                                                                  1001
       DO 1 K=1,M
                                                                                  1002
       IF(ISTAT(K).EQ.1) GO TO 1
                                                                                  1303
       REDCOS(K) = REDCOS(K) - DIFF*(BITNY(II, IHEAD(K)+1) -
                                                                                  1004
          BIINV(II.ITAIL( K)+1))
                                                                                  1005
     1 CONTINUE
                                                                                  1006
       DO 3 K=MP1.N
                                                                                  1007
       IF (ISTAT(K).EQ.1) GO TO 3
                                                                                  1008
       REDCOS(K) = REDCOS(K) - DIFF*B1INV(II.K-M+1)
                                                                                  1209
     3 CONTINUE
                                                                                  1010
C
          UPDATE THE FIRST ROW OF BILLY AFTER CHANGING CTIME
                                                                                  1011
C
                                                                                  1012
C
                                                                                  1013
       DO 10 I=2.NMMP1
       B1[NV(1.1)=B1[NV(1.1)+D[FF+R1[NV(][.])
                                                                                  1014
                                                                                  1015
  10
       CONTINUE
                                                                                  1216
C
          UPDATE VALUE OF THE OBJECTIVE FUNCTION
                                                                                  1017
Ċ
                                                                                  1018
C
                                                                                  1019
       XB1(1) = B1[NV(1.NMMP1)]
```

RETURN1 END 1020 1021

# Original Subnetwork Analysis Program: Flowchart





### APPENDIX D

### Monte Carlo PERT Simulation Program

The Monte Carlo PERT Si illation Program will generate a random sample of network completion times. The required input is

- (a) an acyclic network with one sink,
- (b) parameters describing each activity's completion time distribution, and
- (c) the size of the random sample to be generated.

  Currently, the program generates each activity's random sample of completion times from a chi-square distribution with 3 degrees of freedom that has been linearly transformed to have specified 15-th and 85-th percentiles. The activity time distribution can be <u>easily</u> changed. The basic output is the ordered sample of random network completion times and the corresponding empirical distribution function. The critical paths associated with the sample of network completion times are not determined.

The generation of the random sample of network completion times involves only one network but varying values of the individual activity completion times. It is computationally faster to find the network completion time for a new set of activity completion times by "updating" the network completion time for a previous set of activity completion times than it is to start all over each time. Since the Simplex Algorithm applied to the dual of the PERT problem is ideally suited for this type of "updating", the basic computational technique for determining the network completion times is the Simplex Algorithm (see e.g., G. Hadley, Linear Programming).

A listing of the Monte Carlo Simulation Program is given at the end of this appendix.

# Specific Input Instructions:

- Card 1. Col. 1-3: The number of activities in the network, Format (13).
  - Col. 4-6: The number of nodes in the network, Format (13).
- Card 2. Col. 11-15: The number of random network completion times to be generated, Format (I5).
  - Col. 21-25: The number of parameters needed for generating the random activity completion times, Format (15).

# For each activity one card with:

- Col. 11-15: The origin node of the activity, Format (15)
- Col. 21-25: The terminal node of the activity, Format (I5)
- Col. 31-40: Parameter 1. The 15-th percentile of the activity's completion time distribution, Format (F10.4).
- Col. 41-50: Parameter 2. The 85-th percentile of the activity's completion time distribution, Format (F10.4)

The nodes should be numbered 1, 2, ..., n with the sink being number n.

## Example:

The program's input and output are illustrated in terms of the network in Figure D-1.

Figure D-1. Monte Carlo PERT Simulation Program Example Network

50 22					
58 33	5	2			
01	ĩ	2 2			
02	8 2	12	336.27	429.47	
03	2	3	57.47	89.96	
04	2	4	57.47	89.96	
05	2	5	57.47	89.96	
06 07	2	6 7	57.47 57.47	89.96 89.96	
08	2 2 2 2 3 4	8	68.	107.95	
09	4	8	68.6	107.95	
10	5	8	68. 0	107.95	
11	6	8	68.46	107.95	
12	7 2	8	68. 36	107.95	
13		8	150.36	193.49	
14	6	10	333.96	403.85	
15	3 7	9	333.96	403.85 409.85	
16 17	ıí	11 18	355.10 141.75	221.90	
18	10	13	672.36	783.11	
19	9	14	560.89	660.00	. 6≥
20	ģ	15	560.89	660.00	₹0
21	9	16	560.89	660.00	Si
22	11	17	542.80	638.71	
23	12	18	111.10	173.92	88
24	18	19	256.03	346.98	<b>5</b> €
25	12	19	302.80	400.67	<b>8</b> .
26	12	20	311.95	410.71	
27	11	21	423.58	530.74	28
28 29	12 19	22 20	315.35 7.66	415.71 11.99	IF 1 LEG
30	20	21	16.77	22.55	#1
31	21	22	11.49	17.99	<b>4</b> >
32	22	23	39.54	48.87	<b>3</b> 3
33	12	26	301.91	400.86	<b>Z</b> E
34	5	26	767.09	892.74	W.
35	12	27	350.31	460.06	<u>&gt; \( \) \( \) \( \) \( \) \( \)</u>
36	12	24	382.32	464.98	<b>SE</b>
37	12	25	385.28	461.54	3 E
38	25	24	11.49	17.99 23.00	_
39 40	24 26	23 27	16.28 7.66	11.99	
41	27	25	20.86	28.29	
42	4	28	810-17	976.10	
43	23	29	15.32	23.99	
44	28	30	15.32	23.99	
45	14	31	57.47	89.96	
46	16	31	49.81	77.96	
47	15	31	53.64	83.96	
48	17	31	88.12	137.94	
49 50	31 32	32 13	3.83 49.81	6.00 77.96	
51	13	33	109.01	152.63	
52	11	32	745.50	811.32	
53	10	32	714.74	799.83	
54	30	1.4			
55	30	16			
56	30	15			
57	29	17			

## SAMPLE OUTPUT

INITIAL INPUT

PAR	INUME SPECIFIED										,			•		-												,	••4							•		1		•							\ <u>'</u>	*			
PARAMETER 4	I ACINE SPECIFICUL																						•													S					\ \ \ \	000						, ,			
PARAMETER 3	ייייר ארברורונטו						,												:		•		•					2										2	,												•
PARAMETER 2	0.0	607 4 700	89-9600	89.7600	89.9600	89.9600	89.9600	107.9500	107.9500	107.9500	107.9500	0004-101	603 8500	403-8500	409.8500	221.9000	783.1100	0000.099	660.0000	660.0000	638.7100	173.9200	346.9800	400.6700	410.7100	530.7400	11 9900	22 6500	17.9900	48.6700	400.8600	892.7400	464. 9800	461.5400	17.9900	23.0000	11.9900	976-1000	23.9900	23.9900	89.9600	77.9600	93.9500	137.9400	2000	152.4300	611.3200	799.8330	0.0	0.0	
PARAMETER 1	0.0	336-2700	57.4700	57-4700	57.4700	57.4700	57.4700	68.9630	68.9600	0096-89	00000	150.3600	333.9600	333-9600	355.1000	141.7500	672.3600	260.8900	260.8900	560.8500	542.8000	111-1000	256.0300	302.8000	311.9500	315 3500	7.6600	14.7700	11.4900	39.5400	301.9100	0010.000	382.3200	385.2800	11.4900	16.2800	20 9400	810.1700	15.3200	15.3200	57.4700	49.8100	23.6400	88.1200		109.0100	745.5000	714.7400	0.0		
TERMINAL	7	17	m	•	×	•	<b> -</b>	<b>10</b> (	•	D 60	•	•	9	•	=	97	13	*	<u>5</u>	<b>1</b> !	1	<b>80</b> (	61	2;	3;	7,7	202	2 2	22	2	*;	• •	**	. 52	54	23	52	82	53	2	£	<b>#</b> ;	ก็	1 P	:=	) E	32	32	<b>:</b>	• •	25
ORIGIN	-	•	~	~	7	7	ν.	m ·	• •	۸ «	-	. 2		m	<b>~</b>	1	9	•	<b>o</b> (		= :	71	<b>0</b> ?	7:	7:	1.2	::	20	77	22	77	, :	:2	12	25	54		*	23	28	<b>1</b>	9 1	<u>:</u>	==		1	=	0	D C	9 5	22
CTIVITY	-	7	•	•	'n	•	-	<b>.</b>		2:	: 2	13	*1	15	21	11	3	5	20	17	22	2	*	9;	• ;	287	200	30	16	32	93	, ,	'n	7.0	7	<b>.</b>	7	7	ţ	*	\$	:		0 0	9	215	25	53	*		21

	0.155870+04
TRIALS ARE AS FOLLOWS: (TIME/OBSERVED PERCENTILE)	0.153270+04
AE AS FOLLOWS: (TIM	0.153220+04
•	0-152120+04
HE CRITICAL PATH TIMES FOR	0.148370+04

2

5

7

8

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11

12

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16

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18 19

20

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## PROGRAM LISTING

```
C
 C
          MONTE CARLO PERT
       IMPLICIT REAL *8 (A-H, N-Z)
          FOR THE SAKE OF IDENTIFYING THE APPROPRIATE DIMENSIONS. LET
 C
 c
                M = THE NUMBER OF ACTIVITIES IN THE NETWORK
 C
                NMM = NUMBER OF NODES IN THE NETWORK
 C
                NMMP1 = NMM + 1
 C
                N = M + NMM
 C
                NTRIAL = NUMBER OF SIMULATED SETS OF ACTIVITY
 C
                COMPLETION TIMES
 C
                NPARM = NUMBER OF PARAMETERS NEEDED FOR GENERATING RANDOM
                ACTIVITY COMPLETION TIMES FROM A PARTICULAR DISTRIBUTION
 C.
 C.
 C
 C
       INTEGER TAIL( M).HEAD( M).PARM(M.NPARM).TIMES(NTRIAL)
 C
       DIMENS (ON BIINV(NMMP1.NMMP1).CTIME(N).XB1(NMMP1).Y1(NMMP1)
 C.
       DIMENSION REDORS(N).ISTAT(N).INHASE(NMM).CDF(5).NSPEC(20)
 C
 C
          CURRENTLY THE DIMENSIONS ARE SET FOR
 C
                M=60
 C
                NMM=40
                NTRIAL=2000
       COMMON BIINV.REDCOS.CTIME.XRI.INBASE.HEAD.TAIL.NMMPI.NMM.N.ISTAT
       COMMON M.MP1
       INTEGER TAIL(60) . HEAD(60) . TRIAL . NSPEC(20)
       DIMENSION INBASE (40) . PARM (60.5) . CDF (5) . TIMES (2000)
       DIMENSION BILNV(41.41).CTIME(100)
       DIMENSION X41(41).Y1(41).REDCOS(100).ISTAT(100)
       DATA NSPEC(1).NSPEC(5).NSPEC(9).NSPEC(13).NSPEC(17)/5**(NON*/
       DATA NSPEC(2).NSPEC(6).NSPEC(10).NSPEC(14).NSPEC(18)/5**F SP*/
       DATA NSPEC(3), NSPEC(7), NSPEC(11), NSPEC(15), NSPEC(19)/5**ECIF*/
       DATA NSPEC(4) .NSPEC(8).NSPEC(12).NSPEC(16).NSPEC(20)/5**IED) */
          M = THE NUMBER OF ACTIVITIES IN THE NETWORK
          NMM = THE NUMBER OF NODES IN THE PERT NETWORK
 C
                     M, NMM
       PFAD(5.100)
 100
       FORMAT (213)
       N=NMM+M
       MP1=M+1
       NMMPI=NMM+1
       TRIAL = C
 C
 C
          SIMULATION VARIABLES
 C
 C
               NTRIAL = NUMBER OF SIMULATED SETS OF ACTIVITY
 C
               COMPLETION TIMES
               NPARM = NUMBER OF PARAMETERS NEEDED FOR GENERATING RANDOM
 C
                ACTIVITY COMPLETION TIMES FROM A PARTICULAR DISTRIBUTION
 C
 C
          TIMES = VECTOP CONTAINING THE OPTIMUM VALUE FOR FACH TRIAL
          PARM(I+1) = THE LOWER PERCENTILE POINT FOR THE I-TH ACTIVITY
C
          PARM(1.2) = THE UPPER PERCENTILE POINT FOR THE I-TH ACTIVITY
 C
r
• C
       READ (5.2501) NTRIAL NPARM
```

THE ACTIVITIES ARE DESCRIBED IN TERMS OF THEIR NODES

'n

```
107
C
          II=THE TAIL NODE, THE ORIGIN NODE
                                                                                     60
C
          JJ=THE HEAD NODE. THE TERMINAL NODE
                                                                                     61
                                                                                     62
      DO 610 I=1.M
                                                                                     63
      READ(5,2501) II.JJ. (PARM(I.J).J=1.NPARM)
                                                                                     64
                                                                                     65
2501
      FORMAT(10x,15,5x,15, 5x,5F10,4)
      TAIL(I) = II
                                                                                     66
  610 HEAD(I)=JJ
                                                                                     67
      NNPARM = 4*NPARM
                                                                                     68
                                                                                     69
      DO 222 I=1.NNPARM
  222 NSPEC(I) = BLANKS
                                                                                     70
                                                                                     71
      WRITE(6.2700)
                                                                                     72
2700
      FORMAT (1H1.15X. INITIAL INPUT!)
                                                                                     73
      WPITE(6,2701)
                                                           PARAMETER 1
                                                                                     74
                                             TERMINAL
2701
      FORMAT (1HO, 10X, 'ACTIVITY
                                  ORIGIN
                                                            PARAMETER 51)
                                                                                     75
     *APAMETER 2
                        PARAMETER 3
                                          PARAMETER 4
                                                                                     76
      WRITE (6,2509) (NSPEC(I),I=1,20)
                                                                                     77
 2509 FORMAT (41X,4A4,4(1X,4A4))
                                                                                     78
      DO 2704 I=1.M
2704
      WPITE(6,2702) I.TAIL(1).HEAD(1).(PAPM(1.J).J=1.NPARM)
                                                                                     79
                                                                                     80
2702
      FORMAT (1H .13x.13.5x.13.7x.13.1x.5(7x.F10.4))
                                                                                     81
                                                                                     82
      DO 104 I=1.NMM
                                                                                     83
  104 INBASE(I)=M+I
                                                                                     84
      DO 2001 J=1.M
                                                                                     85
2001
      ISTAT(J)=0.
      DO 2002 J=MP1,N
                                                                                     86
                                                                                     87
2002
      ISTAT(J)=1
                                                                                     88
      DO to II=1.NMMP1
                                                                                     89
      DO 12 L=1.NMMP1
                                                                                     90
   12 B1INV(L.TI) = 0.
                                                                                     91
   10.81INV(11.11) = 1.
                                                                                     92
      DO 30 I=1.NMM
                                                                                     93
   30 \times B1(1) = 0.
                                                                                     94
      XB1(NMMP1) = 1.
                                                                                     95
      TOLR1=1.00-10
                                                                                     96
C
      DO 55610 I=MP1.N
                                                                                     97
                                                                                     98
55610 CTIME(I) = 0.
                                                                                     99
      CONTINUE
350
                                                                                    100
C
C
      GENERATE A SET OF ACTIVITY COMPLETION TIMES
                                                                                    101
                                                                                    102
C
                                                                                    103
      TRIAL = TRIAL + 1
                                                                                    104
      CALL PANTIM (CTIME. PAPM. M)
                                                                                    105
      CALL BINVA (82801)
          START THE SIMPLEX ALGORITHM
                                                                                    106
C
                                                                                    107
         SOLVE THE DUAL PROBLEM
C
          THE NUMBER OF VARIABLES IS M REAL + NMM SLACKS
                                                                                    108
C
          FOR A TOTAL OF N VARIABLES
                                                                                    109
C
                                                                                    110
 2800 DO 23 J=1.N
                                                                                    111
                                                                                    112
      RATS = 0.
      IF (ISTAT(J).EQ.1) GO TO 52800
                                                                                    113
      IF (J.GT.M) GO TO 22
                                                                                    114
      RATS = -81INV(1.HEAD(J)+1)+81INV(1.TAIL(J)+1) + CTIME(J)
                                                                                    115
      GO TO 52800
                                                                                    116
                                                                                    117
   (1+M-L.1)VN118-= STAP SS
                                                                                    114
52800 REDCOS(J)= RATS
```

23 CONTINUE

```
108
22800 CONTINUE
                                                                                     120
       IRMAX=1
                                                                                     121
       PMAX=PEDCOS(1)
                                                                                     122
                                                                                     123
       DO 24 J=2.N
       IF (REDCOS(J) .LE. RMAX) GO TO 24
                                                                                     124
                                                                                     125
       RMAX=REDCOS(J)
                                                                                     126
       I PMAX= J
24
      CONTINUE
                                                                                     127
       IF(RMAX .LF. TOLR1) GO TO 401
                                                                                     128
22824 CONTINUE
                                                                                     129
      DO 26 L=1.NMMP1
                                                                                     130
       IF (IRMAX.GT.M) GO TO 50026
                                                                                     131
      Y1(i) = -H1INV(L.TAIL(IRMAX)+1)+B1INV(L.HEAD(IRMAX)+1)
                                                                                     132
      GO TO 26
                                                                                     133
50026 \text{ Y1(L)} = B1INV(L, IRMAX-M+1)
                                                                                     134
                                                                                     135
   26 CONTINUE
                                                                                     136
      Y1(1) = Y1(1) - CTIME(IRMAX)
      NUMBER=0
                                                                                     137
                                                                                     138
      DC 27 L =2 . NMMP1
                                                                                     139
27
       IF(Y1(L) .LE. TOLR1)
                                NUMBER=NUMBER+1
                                                                                     140
       IF(NUMBER .EQ. NMM) GO TO 403
      RMIN=.99D 20
                                                                                     141
                                                                                     142
       IRMIN=0.
                                                                                     143
      DO 32 II=2.NMMP1
                                                                                     144
      IF(YI(II).LE. TOLRI) GO TO 32
      RATS =X81(II)/Y1(II)
                                                                                     145
                                                                                     146
      PREPATS-PMIN
                                                                                     147
      IF(RR .GF. 0.DO) GO TO 32
                                                                                     148
      RMIN=RATS
      [RMIN= II
                                                                                     149
32
      CONTINUE
                                                                                     150
      DC 33 J=2.NMMP1
                                                                                     151
                                                                                     152
      WW=RIINV(IRMIN .J)/Y1(IRMIN )
                                                                                     153
      DO 37 L=1.NMMP1
37
      31[NV(L.J)=B1[NV(L.J)-ww*Y1(L)
                                                                                     154
                                                                                     155
33
      BITNV(IRMIN . J)=WW
                                                                                     156
C
          UPDATE THE BASIC VARIABLES: INBASE AND XB1
                                                                                     157
C
                                                                                     158
C
      ISTAT(INBASE(IRMIN-1))=C
                                                                                     159
                                                                                     160
      ISTAT(IRMAX)=1
                                                                                     161
      INHASE (IRMIN-1)=IRMAX
      W=XBI(IRMIN )/YI(IRMIN )
                                                                                     162
                                                                                     163
      DO 38 [=1.NMMP1
                                                                                     164
      XR1(I) = XR1(I) - Y1(I) * W
38
                                                                                     165
      XB1 (TRMIN )=W
      GO TO 2800
                                                                                     166
      WRITE(6,530)
                                                                                     167
403
      FORMAT(1H0.5X. *NO FEASIBLE SOLUTION EXISTS. CHECK YOUR INPUT DATA
                                                                                     168
530
                                                                                     169
     *. * )
      WRITE(5.850)
                                                                                     170
                                                                                     171
850
      FORMAT (1H1)
                                                                                     172
      GD TO 949
                                                                                     173
C
         END OF THE SIMPLEX ALGORITHM
                                                                                     174
C
                                                                                     175
                                                                                     176
      TIMES(TRIAL) = BITNV(1.NMMP1)
                                                                                     177
      IF (TRIAL.LT.NTRIAL) GO TO 350
                                                                                     178
C
```

INBASE IS A SET OF NMM INTEGER VARIABLES WHICH INDICATE THE

```
109
 C
           COMPOSITION OF THE CURRENT BASIS. FOR EXAMPLE.
                                                                                     180
 C
                INBASE(K) = 7
                                 IMPLIES THAT THE K-TH COLUMN IN THE BASIS B
                                                                                     181
 C
                                 COPRESPONDS TO THE 7-TH VARIABLE
                                                                                     182
 C.
                                                                                    183
 C
                                                                                    184
 C
           ISTAT INDICATES THE BASIC STATUS OF FACH VARIABLE
                                                                                    185
                                IMPLIES THAT THE K-TH VARIABLE IS IN THE
 C
                ISTAT(K) = 1
                                                                                    186
                                                                                    187
                               DUAL BASIS
                               IMPLIES THAT THE K-TH VARIABLE IS NOT IN THE
 C
                ISTAT(K) = C
                                                                                    188
 C
                               DUAL BASIS
                                                                                    189
 C
                                                                                    190
                                                                                    191
 C
 C
                                                                                    192
 C
                                                                                    193
 C
           CRDER THE RANDOMLY GENERATED NETWORK COMPLETION TIMES
                                                                                    194
                                                                                    195
 3000
        LIMIT = NTRIAL
                                                                                    196
        IPASS = NTRIAL-1
                                                                                    197
        ICHNG = 1
                                                                                    198
                                                                                    199
        DO 4001 J=1. IPASS
                                                                                    200
        LIMIT = LIMIT-1
        IF (ICHNG.FQ.0) GO TO 3060
                                                                                    201
        ICHNG = 0
                                                                                    202
                                                                                    203
        DO 4002 I=1.LIMIT
        IF (TIMES(I)+LF+TIMES(I+1)) GO TO 4002
                                                                                    204
        TEMP = TIMES(I+1)
                                                                                    205
                                                                                    206
        TIMES(I+1) = TIMES(I)
                                                                                    207
        TIMES(I) = TEMP
                                                                                    208
        ICHNG = 1
 4002
        CONTINUE
                                                                                    209
 4001
        CONTINUE
                                                                                    210
                                                                                    211
           DESCRIBE THE ORDERED NETWORK COMPLETION TIMES
 C
                                                                                    212
                                                                                    213
 3060
        WP1 TE(6.9662)
                                                                                    214
       FORMAT (1H1)
                                                                                    215
 9662
        WRITE(6.3012) NTRIAL
                                                                                    216
       FORMAT (1Hg.10%, THE CRITICAL PATH TIMES FOR ". 15." TRIALS ARE AS
 3012
                                                                                    217
       * FOLLOWS: (TIME/OBSERVED PERCENTILE)+)
                                                                                    218
                                                                                    219
       LINF = (NTRIAL+4)/5
                                                                                    220
       DO 3050 J=1.LINE
        12 = (J-1)*5+1
                                                                                    221
        13 = J*5
                                                                                    222
        ICNT = 0
                                                                                    223
        IF (NTRIAL-12+1.LT.5) I3= NTRIAL
                                                                                    224
                                                                                    225
       DO 3051 K=12.13
        ICNT = ICNT+1
                                                                                    226
       CDF(ICNT) = DFLOAT(K)/DFLOAT(NTRIAL)
                                                                                    227
 3051
                                                                                    228
        WRITE (6.3011) (TIMES(1).1= 12.13)
       FORMAT(1H0.5X.5(6X.F15.5))
                                                                                    229
 3011
                                                                                    230
       WRITE (6,3013) (CDF(K),K=1,ICNT)
       FORMAT (6x.5(6x.F15.5))
                                                                                    2 31
 3013
                                                                                    232
 3050
       CONTINUE
                                                                                    233
. 999
       STOP
                                                                                    234
       FND
       SUBROUTINE BINVA(+)
                                                                                    235
                                                                                    236
        IMPLICIT REAL +8 (A-H.O-Z)
       CCMMCN HIINV.REDCOS.CTIME.XB1.INBASE.THEAD.ITAIL.NMMPI.NMM.N.ISTAT
                                                                                    237
                                                                                    238
       COMMON M.MPI
```

DIMENSION ISTAT(100) . THEAD(60) . ITAIL(60) . XBI(41)

```
DIMENSION BIINV(41,41). INBASE(40), CTIME(100), REDCOS(100)
 C
                                                                                   241
 C
           UPDATE THE FIRST ROW OF BIINV AFTER CHANGING CTIME
                                                                                   242
 C
                                                                                   243
        DO 1 1=2.NMMP1
                                                                                   244
                                                                                   245
        B1INV(1.I) = 0.0
•
        DO 1 J=2.NMMP1
                                                                                   246
      1 BIINV(1+1) = BIINV(1+1) + BIINV(J+1) +CTIME(INBASE(J-1))
                                                                                   247
 C.
                                                                                   248
 C
           UPDATE VALUE OF THE OBJECTIVE FUNCTION
                                                                                   249
 C
                                                                                   250
        XB1(1) = B1INV(1.NMMP1)
                                                                                   251
        RETURNI
                                                                                   252
                                                                                   253
        END
        SUBPOUTINE RANTIM (CTIME.PARM.M)
                                                                                   254
                                                                                   255
 C
        SURPOUTINE RANTIM GENERATES M RANDOM TIMES FROM A SPECIFIED
 C
                                                                                   256
       DISTRIBUTION WITH PARAMETERS CONTAINED IN PAPM(60.5) AND RETURNS
 C
                                                                                   257
 C
                                                                                   258
        WITH THE RESULTS IN CTIME(99).
                                                                                   259
 C
        IMPLICIT REAL *8 (A-H.O-Z)
                                                                                   260
       DATA J/0/. TY/19447/. TPI/6.2831853/
                                                                                   261
       DIMENSION PARM(60.5), CTIME(99), SAVTIM(99)
                                                                                   262
                                                                                   263
        IF (J.NE.0) GO TO 30
 C
                                                                                   264
 C
       THE FOLLOWING GENERATES A CHI SQUARE RANDOM DEVIATE WITH 3 DE S
                                                                                   265
            TRANSFORMED TO MAKE THE LOWER POINT CORRESPOND TO THE 15-TH
                                                                                   266
 C
 C
            PERCENTILE AND THE UPPER POINT CORPESPOND TO THE 85-TH PERC.
                                                                                   267
 C
                                                                                   268
 C
       PARM(3.1) = THE PERCENTILE DIFFERENCE
                                                                                   269
                                                                                   270
 C
                                                                                   271
       DO 5 I=1.M
                                                                                   272
       PARM(1.3) = PARM(1.2) - PARM(1.1)
                                                                                   273
 5
       IF (PARM(I,3).EQ.0) CTIME(I) = PARM(I.1)
                                                                                   274
 30
        J = J+1
                                                                                   275
       IF (MDD(J.2).FQ.1) GO TO 20
                                                                                  276
 C
       DO 15 I=1.M
                                                                                   277
       IF (PARM(I, 3).FQ.0 ) GO TO 15
                                                                                   278
                                                                                  279
       CTIME(I) = SAVTIM(I)
       CONTINUE
                                                                                   280
 15
                                                                                   281
       RFTURN
                                                                                  282
• C
                                                                                  283
 C
           GENERATE A PAIR OF COMPLETION TIMES FOR EACH ACTIVITY.
 C
                                                                                  284
           THE BOX-MULLER METHOD IS USED TO GENERATE A PAIR OF
                                                                                  285
 C
 C
                                                                                  286
           NCRMAL DEVIATES
                                                                                   287
           U1 AND U2 = UNIFORM RANDOM NUMBERS
 C
 C
           W#DSIN(AN) = STANDARD NORMAL RANDOM VARIABLE
                                                                                  288
 C
           W+DCOS(AN) = STANDARD NURMAL RANDOM VARIABLE
                                                                                  289
           CHI3 = A CHI-SQUARE RANDOM VARIABLE -- GENERATED USING THE
                                                                                  290
 C
                  METHOD OF WILSON AND HILFFRTY - PROC. NAT. ACADEMY OF
 C
                                                                                  291
                                                                                  292
 C
                  SCIENCE, 1931
          C1 AND C2 TRANSFORM THE CHI-SQUAPE WITH 3 D.F.
                                                                                  293
• C
                                                                                  294
 C
                                                                                  295
 20
       DO 3002 1=1.M
       IF (PARM(1.3).EO.0) GD TO 3002
                                                                                  296
                                                                                  297
       ty = 1y *65539
       IF (IY) 3015.3016.3016
                                                                                  298
                                                                                  299
       IY = IY + 2147483647 + 1
 3015
```

3016	YFt =IY
	U1 = YFL+.465613F-9
	IV = IV*65539
	IF (IY) 3025,3026,3026
3025	IY = IY + 2147483647 + 1
3026	YFL= IY
	U2 = YFL*.465613F-9
	W =-2.*DLOG(U2)
	W = DSORT(W)
	AN = TPI+U1
	C2 = 4.51927/PARM(I.3)
	C1 = .75777 - PARM(I, 1) * C2
	CTIMF(I) = ((.392530614*W*DSIN(AN)+1.335416269)**3-C1)/C2
	SAVTIM(I) = ((.392530614*W*DCOS(AN)+1.335416269)**3-C1)/C2
3002	CONTINUE
	RETURN
	END

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